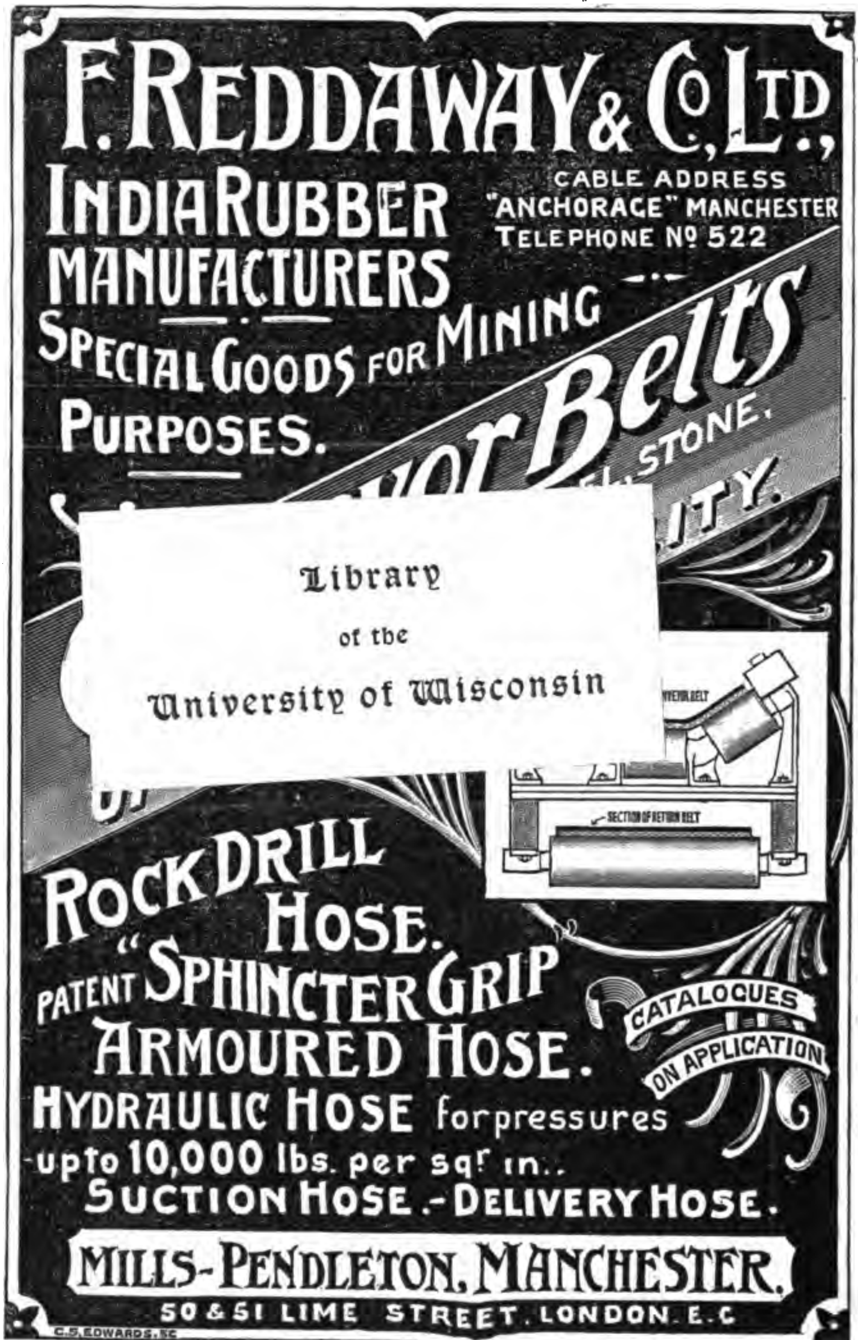
THE MECHANICAL EQUIPMENT OF COLLIERIES.

C. M. PERCY.


F. REDDAWAY & Co. LTD.,
INDIA RUBBER MANUFACTURERS
CABLE ADDRESS "ANCHORAGE" MANCHESTER
TELEPHONE No. 522
SPECIAL GOODS FOR MINING PURPOSES.
Belts
STONE.
SECTION OF RETURN BELT
ROCK DRILL HOSE.
PATENT "SPHINCTER GRIP" ARMOURED HOSE.
CATALOGUES ON APPLICATION
HYDRAULIC HOSE for pressures up to 10,000 lbs. per sq. in..
SUCTION HOSE. - DELIVERY HOSE.
MILLS-PENDLETON, MANCHESTER.
50 & 51 LIME STREET, LONDON, E.C.

"The Mechanical Equipment of Collieries,"

DEALING WITH

MOTIVE POWER. STEAM BOILERS. AIR-COMPRESSING MACHINERY. ELECTRICITY. VENTILATION. HAULAGE. PUMPING. ROPES IN COLLIERY USE. PIT SHAFT GUIDES. HEADGEARS AND PIT BANKS. WINDING ENGINES. DEALING WITH COAL AT BANK. WASHING AND COKING.

THE
MECHANICAL EQUIPMENT
OF COLLIERIES.

BY THE LATE

C. M. PERCY, F.G.S., M.I.M.E., M.I.Mech.E.

Principal of the Wigan Mining College.

AUTHOR OF

"The Mechanical Engineering of Collieries,"
"Mine Rents and Mineral Royalties,"
"Mining in the Victorian Era," etc.

COMPLETED AND EDITED BY

FRANK PERCY, M.I.M.E., A.M.I.Mech.E.

Lecturer in Mechanical Engineering and Drawing in the Wigan Mining College,

AND

GEORGE H. WINSTANLEY, F.G.S., M.I.M.E.

Gold Medallist; Certified Colliery Manager;
Lecturer in Mining in the Victoria University of Manchester;
Formerly Lecturer in Mining in the Wigan Mining College.

MANCHESTER:

JAMES COLLINS & KINGSTON LIMITED,
4, SOUTHGATE.

1905.

Dedication.

TO THE MEMORY OF ITS LATE AUTHOR,

CORNELIUS McLEOD PERCY,

THIS VOLUME IS AFFECTIONATELY DEDICATED,

AND COMMITTED TO THE SERVICE OF THE BRITISH MINING STUDENT

AT HOME AND ABROAD,

FOR WHOSE EDUCATIONAL WELFARE AND ADVANCEMENT

HE DEVOTED THE BEST PART OF HIS LIFE,

UNTIL THE END.

FRANK PERCY.

GEORGE H. WINSTANLEY.

August 1905.

PREFACE.

AMONGST the many tasks—each one alone sufficient to fully engage the energies of an ordinary man—to which Cornelius McLeod Percy devoted himself during the later years, and until the closing days of a strenuous life of usefulness, was that represented by the mass of writing which comprises the greater portion of this volume. In the month of June 1903, with the task scarcely finished, he was called upon to lay down his pen, to cease from labour, and enter into a well-earned rest.

It was felt that the work to which he had devoted so much thought and care could not, must not, be allowed to remain hidden from the light of day; that it demanded and deserved from some one an effort to effect its completion and publication.

The present writers—his son on the one hand and his closest colleague during the last fifteen years of his work in mining education on the other—have ventured to undertake that duty, although not without misgivings, well knowing their inability to fill the few gaps in a manner worthy of a place side by side with the rest of the work, and fully alive to the many imperfections and shortcomings in those portions for which they are responsible—imperfections which would have been absent had the author been spared to complete his work.

So far as possible the original manuscript has been printed as it left his pen, the pen of a ready writer, unaltered except in so far as it has been necessary to bring the matter up to date.

In those portions which it has been necessary to add, fortunately not many, the editors have endeavoured to express the views and lay down the principles which they knew to be those of the late author.

Special attention has been given to the illustrations, many of which are detailed drawings of plant and machinery actually installed and working at modern collieries.

Considerable care, too, has been given to the chapter on electricity, the desire of the editors being to place this important subject before their readers in as useful a form as possible, recognising as they do the prominent part which electrical engineering is bound to play in the mechanical equipment of the modern colliery.

Valuable assistance has been rendered by a number of engineering firms specialising in colliery appliances, and the editors have adopted the course of recognising and acknowledging that assistance in the text, wherever they have availed themselves of the information so kindly placed at their disposal.

FRANK PERCY.

GEORGE H. WINSTANLEY.

Sincerely Yours
C. M. Perry

BIOGRAPHICAL SKETCH.

CORNELIUS McLEOD PERCY, 1846-1903.

Cornelius McLeod Percy was born at Newmains, Lanarkshire, Scotland, on the 30th of July 1846, where he spent the early days of childhood. At the age of seven he crossed the border with his parents, who came to live in England. His father, Francis Percy, was in the best and noblest sense a man of the people, who, by self-education, coupled with great natural ability, raised himself, without patronage and without influence, from the lowly condition of a Scottish herd laddie to the forefront rank in the great iron industry—to occupy one of its most important positions.

The early education of Cornelius McLeod Percy commenced in the public schools in connection with the works of Earl Granville, at Cobridge, North Staffordshire, and of the New British Iron Company in South Staffordshire. As an apprentice with the latter, at the age of fourteen, he entered upon the more serious part in the battle of life, and laid the foundation for an energetic career of usefulness in connection with the two great industries of iron and coal.

In 1862 he came to Wigan and entered the service of the Wigan Coal and Iron Company, of whose extensive ironworks his father had become the manager. Having "gone through the mill" in the fitting shops he proceeded to the drawing office, eventually to become the head of that most important department. This position, however

by no means marked finality in his promotion and advancement with the Wigan Coal and Iron Company, in whose service he remained until he embarked on business in a private capacity, in 1882, as a consulting engineer.

HIS CONNECTION WITH THE WIGAN MINING COLLEGE: FROM STUDENT TO PRINCIPAL.

The best part of his life Mr. Percy devoted to the cause of Mining Education; more thoroughly, perhaps, than any other man in Great Britain—certainly more successfully—had he studied from a pre-eminently practical standpoint, the question of technical education in mining generally, and the education and training of the colliery manager in particular. No one more fully appreciated or more perfectly understood the conditions and requirements of the mining student, with whom he achieved immense popularity, not merely because of his own personality (which always had an attraction for younger men), but because of his efforts to promote their individual welfare, and to fit them for important positions in connection with mining at home or abroad.

More than thirty years of the history of the Wigan Mining School is inseparably associated with the life of Mr. Percy, and it is not too much to say that the record of the last thirty years of his life would indeed be the history of the Wigan Mining School during that period.

A student of the school himself in 1862, and lecturer in engineering subjects six years later, would seem to mark sufficiently rapid progress, but it by no means indicates the boundless energy, the zeal, and enthusiasm with which he worked—slaved would be a truer word—to earn for that institution the record which it possessed at his death. New systems of instruction may be introduced, but it is to be doubted if the results, which

after all afford the best measure of success, will even remotely approach the degree of popularity with the student, or attain the high standard in the judgment of independent examination authorities, which invariably and uniformly attended his efforts.

The splendid building which is now the home of the old Mining School, under its new title of the Wigan and District Mining and Technical College, owes not a little for its existence to-day to his indefatigable zeal and untiring devotion to promote its welfare and success. Fortunate it was for the Wigan Mining School, in its less prosperous days, that it had such a man as Cornelius McLeod Percy at the helm: a less devoted, less self-sacrificing man would have yielded in despair, and the ship must surely have foundered and gone down; but with only half a crew to man the decks—he himself doing the work of ten—he weathered the storm and safely steered a course through the sea of difficulties which surrounded and threatened to overwhelm the vessel. All through the night he stood at his post, and when calm came with the dawn he had brought his vessel to a safe anchorage. Then, though he could ill be spared, was he relieved of his command.

His last public appearance at the institution, which he served so well and so long, was the occasion of the first popular lecture delivered in the large Assembly Hall of the new college buildings on the 17th of January 1903. This was the last of a series of free, and immensely popular, illustrated lectures which he inaugurated ten years before. The singularly appropriate title of his last delivery was "The Future of the Empire," in the course of which he dealt largely with the colonies, particularly Australia and New Zealand. A few weeks later, on board the steamship "Orontes," he himself was speeding towards the Antipodes in search of health and rest:

health which he found not; rest, which he had earned, awaited his return.

HIS POLITICAL CAREER.

At one period of his life Mr. Percy figured prominently in the world of politics, and engaged in two parliamentary campaigns. In 1885 he contested the Ince Division of Lancashire, and in 1886 the Borough of Wigan. In each case the fight was a good one, well fought, and though unsuccessful his defeat was by no means overwhelming. His own characteristic explanation of his defeat was, that he was short of votes.

For many years he was a member of the Wigan Town Council, and indeed in every sense played the part of a good citizen ever ready to take his share, or if need be more than his share of the burden and duties of citizenship.

AS AN ORATOR AND WRITER.

As an orator, few men possessed in so marked a degree the fluency of language, the freedom of style, and the eloquence of Mr. Percy. His power to hold, to impress, and to move an audience was remarkable, and no public function in or around Wigan was complete without his presence.

His literary work naturally related to mining subjects, and his "Mine Rents and Mineral Royalties," which went through several editions, earned for him an honorary membership of the Cobden Club, by which it was adopted and distributed. His "Letters on the Eight Hours Movement" (he was a strong opponent of the Eight Hours Bill) attracted a good deal of attention. The "Mechanical Engineering of Collieries," which went through many editions, was a standard work of reference on colliery engineering, whilst he wrote largely on mining and engineering subjects in the "Science and Art of

Mining," of which for many years, to its lasting benefit, he was the editor.

Possessed of unbounded and indomitable energy, he gave of his best to the service of the mining world at large, and the community amongst which he laboured during the greater part of his life in particular. His was the strenuous life—the life of incessant toil for the good of others. He was an ardent worker in the cause of technical education, and much of the good which has been done in this direction in the industrial centres of Lancashire is due to his work and influence.

He was a man of singular resourcefulness, and had a wide grasp of subjects beyond his own domain. An imperialist in the best sense of the word, proud of his country and the British Empire, he would himself have wished for no better praise, for no higher compliment, than to have it said, that in his own particular sphere of usefulness he did his best, and played the part of a good and worthy citizen.

His voyage to the Antipodes was not productive of the good which was anticipated and desired, and he returned to his home in Wigan on the 7th of June, and on the 13th of June 1903 the sands ran out; the machinery of life, prematurely worn out with incessant strain and heavy overload, slowed down and came to rest. A few days later as he was borne to his resting place he passed once more, for the last time, the place which for thirty-four years had been the scene of his labours and activity, the building he had set his heart upon and lived to see accomplished, the institution which had almost become a part of his own life, and within sight of which he was laid to rest at the last.

TABLE OF CONTENTS.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

LIST OF ILLUSTRATIONS.

ELECTRICAL APPLIANCES.

ELECTRIC INSTALLATIONS.

VENTILATING PLANT.

HAULAGE.

ELECTRIC HAULAGE.

PUMPING.

SCREENING PLANT, TIPPLERS, PICKING BELTS, ETC.

THE MECHANICAL EQUIPMENT OF COLLIERIES.

CHAPTER I.

INTRODUCTORY: THEN AND NOW.

IT is forty years since the writer of these pages—a lad fresh from school, and entering the battle of life on optimistic lines, which optimism has not diminished during a lengthened career—commenced a metallurgical and mining training, throughout which engineering always exercised a special fascination; it is hardly necessary to say that engineering plays a much more important part in mining and metallurgy to-day than it did in that bygone period. The remark has not been uncommon that the operations and practice of coal mining have less tendency to change than the operations and practice of other industries; as for example iron and steel manufacture, which has been absolutely revolutionised during the latter half of the nineteenth century, and there are no signs of finality. Such remarks might have had some substratum of accuracy during the first half of the past century—although they would only have been very partially correct even then,—but such remarks have never possessed a shade of accuracy during the second division of the century. No one conversant with mining would make any such suggestion in the opening years of the twentieth century. The writer spent the golden days of childhood in the Black Country district of the County of Stafford in the late fifties, and even in those early days kept an observant eye on mining work. The pit shafts were very shallow, and the banksman and the hooker-on

could well enough chat from their respective locations. The area which supplied each winding shaft was insignificant, and an agricultural field of moderate dimensions would be occupied by more than one working pit shaft. The conveyance in the pit shaft was by means of basket or skip, and guides in the shaft were rare indeed. Persons descending or ascending prevented contact with the sides of the shaft as best they could. The engines were antiquated, the boilers quite in keeping with the engines, and mechanical transmission in the mine itself was a dream. The pick held undisputed sway, and its supremacy in the United Kingdom is maintained even yet. The coal on reaching the top of the pit shaft—because it would be scarcely fair to speak of the pit banks, which really had no existence—was tumbled helter-skelter, without any attempt at cleaning or separation, into the wagons or carts or boats. Such a description would certainly be a gross caricature of coal mining now, and it is the very comprehensive advance and improvement that has been made all along the line that suggested the necessity for writing this work.

There may perchance be an advantage at the very outset in asking the question—what is supposed to be comprised within the fair scope of the Mechanical Equipment of Collieries? and there will be those bold enough to assert that mining altogether is well-nigh brought within its range. Truly there is abundant scope, and yet there is much which, vital to mining, remains outside. Colliery mechanical equipment will fittingly take in any and all machines in the actual operation of coal getting, and the power for working those machines; the conveyance of all materials underground, whether coal going out or materials of construction going in, and the further conveyance of men and materials in the pit shaft; it is hardly in keeping with the age of mechanical progress that any transport at the mines should be otherwise than by machinery. It has been interesting, almost to amusement, in considering the improvements made in various parts of the world, to find that practically all comparisons in America, for example, are as between machinery and mules, and one is forced to the conclusion that until the great force of electricity made its influence felt, the mule was the chief hauling instrument in some parts of the mining world. The means of producing the needful flow of air

for the ventilation of the mine, whether relating to main ventilators fixed at the surface or auxiliary ventilators stationed underground—there is now no efficient and safe and economic method of ventilating a mine except the mechanical. The power for performing all these operations, whether the method may be that of steam or compressed air or electricity, the loading and the unloading of the cages at the bottom of the shaft and at the top of the shaft, mechanical methods have made their influence felt in this matter, and have diminished the wasted time between the windings of a colliery. The handling of the coal from its delivery at the top of the pit shaft until its consignment by rail or road or water to market. Even the preparation of the smallest of the coal, to be used in metallurgical work, and the conversion of that small coal, hitherto almost useless, into valuable coke and other products. Coke manufacture in all its stages is not outside of Colliery Mechanical Engineering.

The drainage of the collieries, which may simply be a trouble during the sinking of the pit shafts, or, as in many cases, a constant labour and very considerable expense when the colliery is at work. Even the sinking of the shafts themselves has for many years been largely a mechanical operation; and probably the writer and his readers will agree that the range of subjects as sketched will suffice to justify the title of the work without trespassing at all excessively upon the special preserves of other mining writers and other mining works. A word might be said in this introduction as to a twofold benefit that has come to the mining community during the last quarter of a century. Mining literature, until far on in the nineteenth century, was practically confined to mining institutes, which were much more exclusive then than now, and their papers and discussions were hardly within reach of the mining worker and the mining student. A great change has come, and year by year the very best of our mining men place at the disposal of their fellows the rich records of their thoughts and experience. The other advantage, which is probably the greater of the two, lies in the facilities for education now placed practically within reach of all ranks and classes. There is no doubt that much of the improvement in our mining appliances, and much of the diminished danger in our mining work, are due to the education

which has been provided, and to a substantial extent utilised by a sufficient number of the mining community—all exercise a healthful influence. The facilities for education in the United Kingdom are rapidly on the increase—such facilities have prevailed in America and on the Continent of Europe for more than one generation,—and such increasing facilities will have a still greater influence on the mining industry. The application of the various forms of energy is on the increase, and it will be in mining by-and-by, as it is already in many other of the world's industries, that nothing will be done by manual labour that is capable of effective and safe and economic accomplishment by mechanical means. It will be necessary even for the ordinary worker in future to have an increased knowledge of the science and practice of mining work, and it is quite certain that the positions of authority will be captured by the ablest, because the most intelligent and highly trained, amongst our miners. There has been very much in the years that are gone of meddle and muddle, waste and mismanagement, in educational arrangements; millions upon millions have been expended upon elementary education, and the average product of elementary schools has been fearfully and wonderfully made; these places have tried to teach too much and have taught very little, and the lad on leaving the elementary school has forgotten in a year all that was endeavoured to be crammed into him in half a dozen years. Our education has been too bookish and altogether insufficiently practical, but a change is coming, and the citizens of the British Empire, although slow to get out of certain grooves, when they do get out of those grooves they accomplish anything and everything that they aim at. What is wanted is that elementary schools shall teach elementary education, and that the higher knowledge directly appertaining to trade and commerce and industry shall be obtainable at the technical schools and colleges which ere many years have passed away will be found in all the great centres. The writer's connection with education—that of the miner especially—has been so long that his readers will pardon what might be considered somewhat of a diversion in this introductory chapter; but after all, the writing of books is not all that the student needs—these books can only at best supplement his own efforts in the classroom and in the laboratory.

CHAPTER II.

MOTIVE POWER AT COLLIERIES:

STEAM—COMPRESSED AIR—ELECTRICITY.

IT has been thought that an appropriate commencement to this work would be to deal with the question of motive power, the amount of which, applied to mines in the United Kingdom and elsewhere, is certainly not less than millions of horse power, entailing an expenditure of a good many millions sterling each year. It is therefore of the first importance that such motive power should be applied as will ensure efficiency together with economy. The latter term, as applied to the provision of power, scarcely entered into the vocabulary of mining authorities of the past; no colliery manager of to-day is worth his salt who does not give it the most serious consideration. Economic colliery power may easily enough make all the difference between a profit and a loss. Safety must ever be kept in mind in colliery operations, but safety is not everything. Collieries are not philanthropic institutions, established to find employment and to provide wages; they are commercial undertakings, whose purpose is profit. There is not great variety in the motive power available for colliery work—nor, for the matter of that, in other work,—and probably there will be no insuperable difficulty in arriving at what is best. There are a few cases in which water power has been, and even yet is, made available. Water flowing past a colliery may be intercepted and usefully harnessed; and even in the mine, when the arrangements have been convenient for collecting all the water with which the mine may abound at a point sufficiently low, the water in descending to its point of collection may well enough be utilised on its way for purposes of haulage and other operations. But such instances

are rare, and have no general application. There will be no possibility of error in concentrating attention and consideration upon steam, compressed air, and electricity.

STEAM.

It is a most reprehensible procedure, but by no means uncommon, to discard a servant who, by length of service, has become less energetic and comparatively less useful. The sense of gratitude, like the milk of human kindness, is not always with us; and there is a very remarkable tendency in certain quarters to speak of steam as an antiquated old servitor, whose day is done, and for whom we have no further use. Personal ingratitude and human want of consideration are easily understood; industrial ingratitude and forgetfulness are quite as wrong. The latter half of the eighteenth century gave us the practical use of steam, and the earlier half of the nineteenth century witnessed the coming of the world into a new existence under its benign influence. Later years have placed at our disposal a form of energy about which we shall say more presently, but what the two centuries that have gone would have been if steam had been unknown is not pleasant to think about.

Will it be wrong in the treatment of the subject to endeavour to be simple as well as practical? Probably not. Much more harm, or rather much less good, is done by assuming too much knowledge on the part of a reader than by assuming too little. In connection with steam the remarkable product coal is ever most prominently identified, and the theory of the formation of that wonderful world's commodity is as fascinating as a romance. Ages ago—time measured not in centuries, but in periods much outside of our ordinary conception—the sun exercised its influence upon the primeval forests, and by a simple but enormously powerful separation of oxygen into the atmosphere and carbon deposited in the earth, commenced that remarkable coal formation the working of whose beds and seams now controls and makes possible the industries of the world. To effect that separation the sun expended some of its store of heat, and in the use of the coal for industrial purposes the elements recombine and the heat is restored. There will be no treatise or deliverance here upon the wonderful and mysterious phenomena of heat of which we know of its pro-

duction and its effects, but as to its real nature the most eminent amongst us are small indeed. For our present purpose it is sufficient to know that the burning of coal produces heat, and that this heat is convertible into mechanical work. Further, we can determine what we call a unit of heat, and we can also determine how much mechanical work a given quantity of heat is capable of, and how much heat can be generated by the influence of a given amount of mechanical work. Let us endeavour to see how much mechanical work theoretically a pound of coal is capable of. We may take it that a fairly average quality has a capacity of 14,000 units of heat in one pound of coal, and that each unit of heat is capable of conversion into 778 units of mechanical work, and 33,000 mechanical units equal one-horse power for a minute; and 33,000 multiplied by 60 equals 1,980,000 mechanical units which are equal to one-horse power for an hour. It is not difficult to show that on this theoretic basis a pound of coal has a capacity of 14,000, multiplied by 778 equals 10,892,000 mechanical units, representing practically five and a half horse power for an hour. On these lines a pair of steam engines of 1000 horse power would only require the consumption of less than one ton of coal in an eight-hour day, representing an expenditure not exceeding ten shillings. Of course, if anything approaching such a condition of things was possible, steam power generated by coal would hold an impregnable position. Theory and practice are never exactly alike; in this particular matter they are nearly as far apart as the poles. It should make a colliery engineer blush to admit it, but even in the twentieth century an average example of the most important class of colliery engine probably does not yield one-fortieth of this result, and a pair of engines—1000 horse power in a ten-hour day—will consume, say, forty tons of coal, representing an expenditure of, say, twenty pounds sterling. Whether steam shall continue to play an important part in colliery work depends upon how near the theoretic capacity of coal and the practical results with steam can be brought nearer together. This leads us to the question—why the enormous discrepancy? The answer is, that it is partly owing to causes beyond control within the limits of present human knowledge, and is partly owing to wilful, reckless, and inconsiderate extravagance. There are cotton mills in many

industrial centres at which the steam engines easily and regularly yield a horse power for an hour by the consumption of two pounds of coal; the millowner has to buy his coal and to pay for its delivery. There are fine modern ships of every nation on which the steam engines as easily and as regularly yield one horse power per hour by the consumption of one and a half pounds of coal; the shipowner has to buy his coal and to pay for its delivery, and every ton of coal carried means a ton of paying cargo less. The colliery owner is, of course, not nearly so bad as he was, but still goes on the even tenour of his way, allowing a consumption in large and important colliery engines of at least as much as eight pounds of coal per horse power per hour, and accepts a situation in which one ton in every twenty of coal production is consumed at the colliery; the colliery owner does not buy his coal. We will deal first with the causes, at present beyond our control, which necessitate so great a difference between theory and practice. Steam is and has been a valuable servant, but its generation and use is dogged with loss at every stage. Even supposing that such loss was avoidable, we are compelled to realise that the theoretic heat capacity assumes the working down of steam to the point of absolute zero of temperature—namely, the point at which no gas and no heat can exist. But this would carry us down to 492 degrees F. below our freezing point, and would be 560 degrees F. below the temperature corresponding with a practically perfect condenser vacuum, and comparing this with the temperature of steam at the highest practicable working pressure—namely, 860 degrees F. of temperature and 250 pounds pressure—represents a loss to start with, in an absolutely ideally perfect steam engine, of two units in every three. But, in addition to this, we have a succession of losses—the water is converted into steam within a boiler, the coal is burnt upon the firegrate of the boiler, perfect combustion is impossible, coal is only partially consumed, a large amount of heat passes away unused in the gases to the chimney, there is loss of heat by radiation and loss between the firegrate and the interior of the boiler. The water from which the steam is generated is abundant and cheap, but whereas the temperature of the furnace in which the coal is burnt amounts to several thousand degrees, the working temperature of the steam is limited to something like 860 degrees F., corresponding

with a pressure of about 250 pounds on the square inch, beyond which the steam tends to break up into its elements. Still the practical result in the engine can be made to yield about one-seventh of the theoretic capacity of the coal, and does yield that proportion in good modern marine and mill engines, and if this result was obtained at collieries the pair of steam engines spoken of just now—1000 horse power—would, in a day of ten hours, consume about seven tons of coal, representing an expenditure of about three pounds ten shillings, and such an expenditure, not exceeding one farthing per horse power per hour, would—it is no exaggeration to say—be quite impossible to beat. But we must still pursue our enquiries, and ask why colliery engines are so extravagant; steam generators are available of the same character as in marine and mill practice. To use steam economically we must convert as much as possible of the heat into mechanical work, and to do this we must commence with the highest possible pressure and end with the lowest possible pressure; the measure of the possible efficiency must be the difference between the two extremes, and all the heat escaping with the exhaust from the engines has evidently not been converted into mechanical work, and is so much heat and work lost. Colliery engines have lacked in expansion and condensing. Does it ever occur to many of us that in a steam engine, using steam without any expansion and without any condensing, that at the end of each stroke we discharge a whole cylinder full of steam of boiler efficiency that has done no work at all? It may be said that such a statement cannot be correct, because mechanical work has been done. That, of course, is so, but the heat converted into mechanical work has been replaced by fresh heat coming into the cylinder from the boiler, and that operation goes on all through the stroke. A very great change has come and is coming over colliery steam engines, and at really good modern collieries, engines without expansion and without condensing—except in some small cases for merely incidental operations—are looked upon with pious horror, and for all important engines on the surface—steam may possibly without disadvantage be taken to the bottom of the pit shafts, but not beyond—steam is used expansively and condensing. The same perfection can hardly be expected to be reached with the whole of the colliery steam engine plant as in our mills and

on our ships, but we might well enough attain a degree of excellence represented by four pounds of coal per horse power per hour, which would not be an expenditure exceeding one halfpenny per horse power per hour.

COMPRESSED AIR.

Steam ought not to be generated in the mine, and ought not to be taken into the mine; the utmost limit that we would allow would be to the bottom of the pit shaft for pumping—we say for pumping, because the facilities for avoiding exhaust, and even vapour, abound in the water of pumping arrangements. Steam has been generated in the mine and, the pit shaft answering as a chimney, the ventilation has been assisted; but how many underground steam boilers have produced disastrous fires by setting up combustion in the coal seams in proximity to the boiler? Steam has been taken into the mine, but the loss of heat so far as the steam is concerned, and the gain of heat so far as the mine is concerned, are incontrovertible arguments against the system. In searching about for a power that could be taken into the mine without inconvenience to the mine, compressed air has obtained and retained a substantial amount of popularity. Provided that the appliances are of proper proportions, there need be hardly any loss of power in the mine, and such influence as the exhaust of compressed air exercised would be beneficial, because of its cooling tendency. This class of power seemed to be capable of great efficiency as well as convenience, and with ordinary care danger could not attend its use. Theoretically all that was necessary was by means of some other mechanical power, steam by preference, to take air in from the atmosphere and compress it to the required pressure, namely, 30, or 40, or 60, or 100 pounds per square inch above the atmosphere, then passing this compressed air into the mine by pipes it would act upon various appliances just like steam. Upon the surface the power of steam became the power of compressed air, and in the mine the power of compressed air became the mechanical work of hauling, and pumping, and tunnelling, and drilling, and coal cutting. And all this has really been done; but the cost is great. Some enthusiasts, in their fervour for compressed air, pronounce the cost inconsiderable, and even argue that practically all the work of the

steam in compressing the air is given back when the air performs mechanical work, but the balance of opinion, based upon experience, is very much the other way. When air is compressed its temperature rises; the cylinders of air compressors afford ready proof of this. When compressed air expands the temperature falls; the snow and frost at the exhaust of machines worked by compressed air show this abundantly. If we could convey the compressed air at its increased temperature into the mine, and, without fall of temperature in transit, use the compressed air, all would be well. In receiving the mechanical work the compressed air would rise in temperature; in expending the mechanical work the air would fall in temperature to its original condition. That happy condition of things is not attainable in practice. Suppose we take 60 degrees F. as a fair average temperature of atmospheric air when the pressure is 15 pounds per square inch absolute, or one atmosphere. Converting the 60 degrees ordinary temperature into absolute temperature makes it 520. Compressing the air to two atmospheres, or 30 pounds, would raise the temperature to 638 absolute; three atmospheres, or 45 pounds, will give a temperature of 718; four atmospheres, or 60 pounds, will give 781; five atmospheres, or 75 pounds, will give 833; and ten atmospheres, or 150 pounds per square inch absolute, will produce a temperature of 1119 degrees F. absolute. Putting this into ordinary temperatures Fahrenheit, we have for two atmospheres 178, for three atmospheres 258, for four atmospheres 321, for five atmospheres 373, and for ten atmospheres 559. Such temperatures could not possibly be maintained, and, if possible, would be attended with very great inconvenience. This is fully recognised by all users of compressed air, and not only is no endeavour made to maintain the temperatures corresponding to the compression, but it is accepted that the temperature, whatever the compression, will fall to the normal condition of the atmosphere, and every assistance is provided to facilitate that fall, and even so far as possible to prevent the rise. The position, therefore, is that this rise of temperature, followed by a fall, represents a loss of efficiency which is easily measured. For two atmospheres the loss is 18 per cent; for three atmospheres, 27 per cent; four atmospheres, 33 per cent; five atmospheres, 37 per cent; ten atmospheres, 49 per cent. The

actual loss is greater than this, which is really the loss that would be experienced in an ideally perfect air-compressor. The rise in temperature is never entirely prevented in the compressing cylinder, and the result is an increase in volume—that is to say, the volume is greater than it would be if this rise in temperature did not take place; therefore we expend mechanical work upon a larger volume than remains available to us afterwards for use. Suppose we endeavour to make an approximate comparison between the use of steam direct and the use of steam through the medium of compressed air. Assume a mechanical efficiency for the steam engine of 80 per cent, and also assume a mechanical efficiency for the air compressor of 80 per cent; then the mechanical efficiency of the air compressor is really 64 per cent. But we have shown that the loss of heat, and therefore work, may be anything from 20 to 50 per cent in the air itself, and the efficiency of the compressed air would not exceed one half of the efficiency of the steam engine. Many of much experience do not place compressed air even so high as this, but a fair average may be taken as set out above. There is neither intention nor inclination to attempt any depreciation of the sterling value of compressed air; it is a safe and useful servant in mining operations, and whilst it was said a little distance back that a colliery manager had to have constantly before him not only safety but efficiency and economy, it can also just as strongly be said that no amount of efficiency and economy can be allowed to diminish the amount of safety. There is no part of any mine, however dangerous, to which compressed air cannot be taken so far as safety and capability of doing work is concerned, and there are some points in the application and use which by receiving attention will increase the efficiency and not diminish the safety. It will have been noted that the loss in efficiency increases with the compression, and good modern practice is to perform the operation in more than one stage, and thus diminish the amount of compression in any one cylinder. The outward cooling, provided the flow of water through the jacket is cold and continuous—otherwise the water will heat, not cool—will suffice. Then between each two cylinders there is a cooler after the fashion of a surface condenser; there is the continuous flow of cold water through the tubes of this vessel, and any heat in the air outside the tubes is extracted,

and the air thus cooled and sent on its way to the next stage. The clearance capacity of the air cylinder should be reduced to insignificance—it is useless to compress air and then immediately allow it to expand,—and the receiver into which the compressed air is delivered should be capacious—that is to say, equal to the volume of compressed air delivered in one minute. Provision should be made for draining the moisture from the receiver. The air compressor should be equal to the volume of air required by all the appliances if working at one time, and the pipes which convey the air down the pit shaft and into the mine should be of such dimensions that the air will not need to flow through the pipes at a linear velocity exceeding one hundred feet per second. Several authorities fix fifty feet per second as the limit. The erroneous notion prevails that a great fall of pressure between the air compressors and the machines doing work is inevitable, and the only ground for the notion is the experience that an air compressor arranged to work at 60 pounds pressure seldom delivers more than one half that pressure to the machine to be worked. Suppose that for every two cubic feet of compressed air required to be used, the air compressors are only capable of delivering one cubic foot; the volume will be delivered but in an attenuated form, and the pressure will have fallen one half. Suppose that the pipes are so insufficient in area that, although the air compressors are equal to requirements, the pipes will not allow the air to pass; then the volume again will be forthcoming but in the attenuated condition, and the pressure cannot be maintained. Insufficient air compressors and insufficient pipe area will not do. Sufficiency of air compressors and insufficiency of pipe area will not do. Insufficiency of air compressors and sufficiency of pipe area will not do. The air compressors must be equal to producing the volume at the pressure required, and the pipes must be sufficient to pass the volume required. This condition being fulfilled there is really no reason why the pressure at the various machines should not be equal to the pressure of the air at the compressor itself. In the great railway tunnels of Mont Cenis and St. Gothard, whilst in construction, compressed air was largely and effectively used in working the drilling and boring machines, and was conveyed a distance of several miles into the tunnels, and the loss of pressure was scarcely sufficient

for recognition, amounting to perhaps about five pounds in about five atmospheres. In collieries we have the advantage of the column of air in the pit shaft itself, which column by its own weight may easily enough add several pounds to the available pressure, so that we may actually have a slightly greater pressure at the machines to be worked than at the air compressors themselves. It is found good practice to place in close association with the machine or engine to be driven by compressed air a receiver, not necessarily of large capacity, equal to say half a dozen double strokes of the cylinders to be supplied, and the air will deliver into the bottom of such receivers and be taken out at the top. The object of these receivers is twofold—namely, to improve the regularity of the supply of compressed air, and to enable any accumulation of moisture to be drained away. The tendency to form ice in the exhaust passages will largely diminish by sending into the cylinder air as dry as possible, because it is not the air that freezes but the water in the air, and the tendency to form ice practically disappears by making the exhaust passages large and straight and short. Common-sense, as well as practical experience, tells us that small and narrow and long passages facilitate the formation of obstructions. The question may be asked why is the exhaust of compressed air so very cold? The answer is fairly simple. When air is compressed from atmospheric pressure to 45 lbs. per square inch above the atmosphere, the corresponding temperature is 321 degrees F. ordinary; and when compressed air at 45 lbs. per square inch re-expands to atmospheric pressure a corresponding reduction takes place. A great deal of the cold is immediately vitiated by the contact with so much larger a volume of air, but sufficient cold remains to produce a frosty condition of things, and to make the engine house very cold indeed. Perhaps a word might be opportune here as to speed of air compressors. There is no reason why engines and machines driven by compressed air should not work well enough at a good speed, say of four hundred piston feet a minute; but high speed in air compression hardly seems desirable for those compressors whose valves are not mechanically controlled. A high speed will prevent effective action of the valves, however well made and fixed, and it must be remembered that the action of an air compressor is

peculiar. The expanding steam in the steam cylinder diminishes the power and the pressure on the steam piston, whilst the compressing of the air in the air cylinder increases the resistance of the air pressure as the stroke progresses. So unequal an action is not conducive to high speeds, and there seems substantial reason why such a piston speed—four hundred feet per minute,—especially as the air compressor may run continuously for hours, should be considered a fair limit. An essential appliance for air compressors, which should work in pairs, is a powerful flywheel, capable of storing as much energy as represents at least a double stroke of the pair of air compressors.

ELECTRICITY.

The two motive powers already dealt with have become classic in their connection with colliery operations—namely, steam, which filled the ninteenth century, and compressed air, which has been familiar to mining men during the latter half of that century. The particular motive power which is exercising an increasing fascination alike upon scientific and industrial men—namely, electricity—is only as yet in its early childhood, but is nevertheless a very sturdy infant, destined in the immediate future to occupy a position in the industrial world second to no other with which we are acquainted now or likely to be acquainted with as time goes on. The wonderful application of electrical energy in late years, crowned by the harnessing of the mighty waterfalls of Niagara, has increased the public and popular craving for electrical applications in all directions. For lighting and for signalling it has become supreme, but its prominent future will be in connection with the performance of mechanical work. Engineers of a practical and economic turn of mind, whose travels have included the American continent, have long been impressed with the enormous potentiality for work in the volumes of water which shoot Niagara in a never-ceasing flow year in year out; the mighty roar of the waters, which was interpreted by the natives before the advent of civilisation as the voice of the gods. The actual amount of the possibility for work in that unique natural feature can only be very approximately determined, but probably it is not an exaggeration to say that there is as much power in the waters, forming a boundary between the Canadian dominion

and the United States, passing over the falls each year, as would be generated if a year's production of the world's coal was utilised for steam generation and applied to the modern steam engines with which we are all acquainted. All this power is there, as free as the air we breathe, and is undiminished by the passage of epochs, and eras, and ages.

There is no real ground or necessity for apology in the fact that the writer deals with this subject—namely, the applications of electricity as a motive power at collieries—in no sense as an electrical expert, but simply as one who has been engaged in colliery operations all his life, and who has watched with fervent interest the introduction of methods and appliances and motive power likely to benefit the mining industry. What is done at Niagara and elsewhere is that another form of energy, such as falling water, is utilised by being converted into electrical energy, which, through a simple flexible wire, can be conveyed not merely hundreds of yards, but in special cases hundreds of miles, and at the end of its journey can be reconverted into mechanical energy performing mechanical work. There are many other locations, not so vast as Niagara, where water power is utilised in this way, and the energy transmitted considerable distances, and it will be well for industrial economy that such facilities and opportunities should not be neglected. We are inclined to rather put on an air of superiority in comparing the things of modern times with the methods and actions of our forefathers, and we drifted into a groove in which we rather smiled at the ancient windmills upon our hills and the water-wheels in our valleys. We did not always remember that the power of the wind and the power of falling water cost us nothing and were inexhaustible, whereas every pound of coal that we produce and consume diminishes the natural wealth of the earth to that extent, and cannot be replaced. It is not simply that the coal used for steam generation was effective and easy of application, but this fact had an influence upon our industrial development and the substitution of coal for other means of producing mechanical power. All important trade and business centres, the towns and cities that make up a country, find special advantages in being located neither on the hills nor in the valleys, but on the

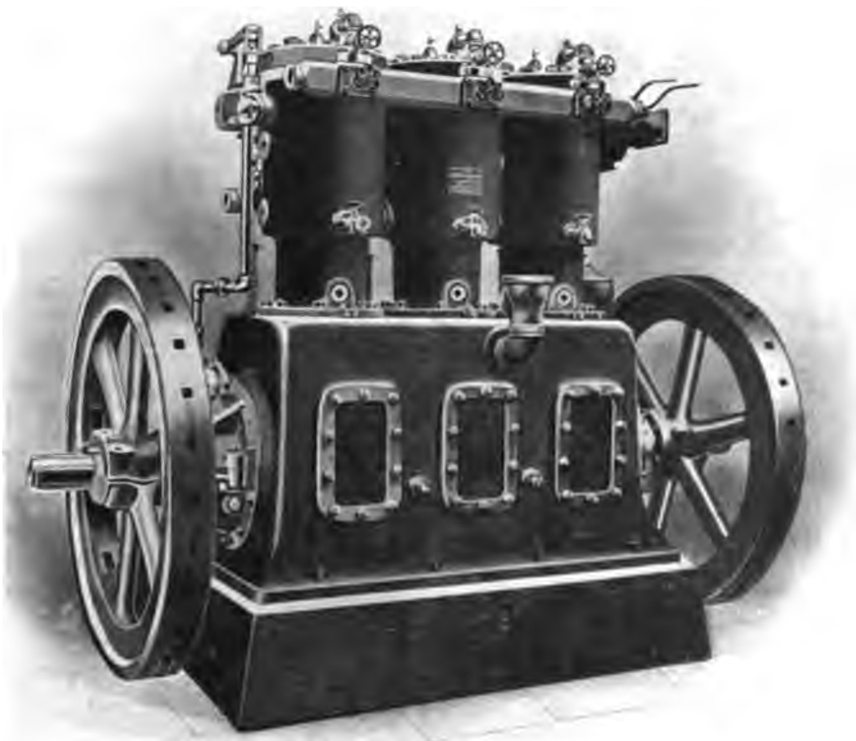
plains. The effectiveness of falling water was confined to the valleys, and therefore the water-wheels of the past flourished there, and mills and works were erected there. But the work that has been accomplished at Niagara has proved by practical demonstration, by means of electrical applications, that we can utilise the water power where it is most effective, and can transmit it to the points at which it can be most advantageously applied. Electrical energy can, of course, be generated by any other motive power—water not being always available,—and at the very numerous electric generating stations steam is the power so applied. Such arrangements encourage the application of the most perfect and economic steam engines, and have given special encouragement to the modern type of steam engine known as the turbine, whose great feature is its direct circular motion, and therefore a practically perfect balanced mechanism, affording to all intents and purposes unlimited speed, thus dispensing with all gearing between the engine that drives and the machine that is driven. The steam engine with which we are all familiar—namely, the reciprocating mechanical arrangement with a backward and forward straight line movement every revolution—is simply incapable of high speed in the proper sense of the term, because in each revolution the piston of the ordinary steam engine comes to absolute rest twice, and it is not difficult to realise that the overcoming the inertia and the *vis inertiæ* of the massive machinery of our best steam engines is opposed to great speed. Engineers have always recognised this, and have endeavoured to effect a remedy by obtaining direct circular action from the steam. When George Stephenson was president of the Institution of Mechanical Engineers, more than half a century ago, the subject was discussed, and he pronounced it impossible of accomplishment. It is safer not to pronounce anything of this kind as impossible. A hundred years ago no one believed that ships would traverse the oceans under the influence of steam, and midway in the last century an eminent scientist, in the person of Dr. Lardner, declared that no ship could make the journey from Liverpool to New York under the influence of steam, because no ship could carry coal enough for the journey. We have plenty of steamers making far greater journeys now. Not much more than thirty years ago, men so eminent in scientific and practical engineering as the late

William Fairbairn and the late Nicholas Wood stated that no mechanical contrivance could pass a quarter of a million cubic feet of air per minute through the workings and passages of an ordinary mine. At the present day such a volume is comparatively insignificant, and mechanical contrivances can give us, if necessary, that volume fourfold. We should never prophesy unless we know. Dr. Lardner was wrong, and he was no mean authority; George Stephenson was found wanting, and few better engineers have adorned the annals of any country; William Fairbairn and Nicholas Wood arrived at incorrect conclusions, and yet they were giants in their day and generation.

The steam turbine is a very admirable machine. It has no reciprocating action, and therefore no dead points, and hardly any mechanism; it gives us direct circular motion at a speed which can be reckoned in thousands of revolutions per minute, and really its velocity is only limited by the quality of the bearings in material and workmanship.

But the generation of electrical energy is not confined to falling water or steam; a vigorous and successful rival has arisen in the gas engine, which, considered very much in the character of a toy a generation ago, is increasing its hold by thousands each year—one firm alone within reach of where these pages are being penned is making and selling a hundred gas engines a week,—and, having already accomplished successfully hundreds of horse power in a single engine, is removing all doubt as to its efficiency at any power, however great. Critics adverse to gas engines say that they are always getting out of order. One firm alone would hardly receive orders for thousands each year if that were the case; but, as a matter of fact, there are gas engines, each of several hundreds of horse power, that have worked continuously day and night for a year without turning a hair. The possibilities of the gas engine are very great. Even with only the expensive illuminating gas of towns available, a gas engine of twenty horse power will not cost more for gas than one halfpenny per brake horse power per hour; and as the gas engine increases in size the consumption of gas per horse power diminishes; but in the years to come, and no great distance ahead, the gas engine will not be worked by expensively made

gas intended for an entirely different purpose, and even now a cheaper product is being used in many cases. The writer, who has never lost his old interest in metallurgical matters, has followed with very great interest the proposals to utilise for power purposes the waste gases from blast furnaces. In his



A Three-Cylinder Westinghouse Gas Engine.

early days a work that came under his direction was the application of blast furnace gas to a range of twenty Lancashire boilers, for the purposes of steam generation, and that installation was so successful that not a pound of coal was used at these boilers, which, under the old arrangement, would have consumed—reckoning a twenty-four hour day and seven working days to a week—an expenditure of many thousand pounds sterling a year. But after doing all such work as this—namely, generating steam and heating the blast—a very great volume of

blast furnace gases remains unutilised, and some of it is being applied to gas engines. It has been necessary, in applying this blast furnace gas as a motive power, to modify the design of the gas engines in which it is used, because a larger volume is needed for a given amount of work. That has not been found to be an insuperable obstacle. Another and greater difficulty is in consequence of the fact that all blast furnace gas is too dirty to be used in its raw state in the gas engine, and will have to be washed before use. That is a mere detail, and the removal of the difficulty may well be left to engineers who have accomplished much greater things than the purification of blast furnace gas. And even all this does not exhaust the opportunities of the gas engine. There is available in every coal-mining country refuse fuel, at present practically valueless, or even worse than valueless, because it cumbereth the mine below and the surface above. That refuse fuel is even already being converted into gas suitable for gas engines, and when the arrangements are properly worked out will be available as gas, not at one shilling and two shillings per thousand cubic feet, but will be brought to the gas engine at a few pence per thousand cubic feet. The advantage which the gas engine possesses will be understood from the defects pointed out in this chapter as harassing the steam engine. In the gas engine the vessel in which the power is generated and in which the power is used are one, and there is not that enormous difference between the temperature which generates the power and the temperature of its use. There is, probably, no form of energy that can be so conveniently and with so little loss transmitted to such a distance as electricity; and by means of cheap gas and effective gas engines a unit of electrical energy, which now costs not less than one penny, need not in the future represent an expenditure of more than a fraction of a penny. One unit of electrical energy, representing one and a third horse power for an hour, may be taken as likely to yield not less than one brake horse power of mechanical work per hour.

Now let us see what is to be said with regard to the application of electricity as a motive power in mining. The unbalanced enthusiast we have always with us, and it is possible enough that his utterances make the development of new ideas

less rapid than a more reasonable advocacy would accomplish. We have some of these who have electricity on the brain, and they argue quite seriously that electricity, before very long, will be the only form of energy in connection with colliery work, and will be used in everything in preference to steam. They say that the most important engine at the colliery consumes something like ten pounds of coal per horse power per hour; that the other engines at the colliery are also in their operation within measurable distance of such a woeful condition of things; whereas, they further say, good modern electrical arrangements would represent a substantially less consumption.

No one has said more or has spoken more strongly than the present writer of the criminal extravagance of colliery engines, and all the utterances in this direction can be traced back to the writer's original deliverances; and no one is more impressed with the excellence of the machinery, whether as steam engines or gas engines, used in the generation of electricity; but it is hardly fair to compare bad steam engines, which stand condemned, with good electrical machinery, which, in a great majority of cases at collieries, would have to be driven by steam, and no doubt the steam would be applied in the best possible steam engines. It would be more fair to compare good steam engines with the suggested admirable electrical application. If colliery steam engines generally are not economical, which may be at once admitted, why not apply the excellence of really good engines to the existing engine arrangements that would assuredly be applied to an electrical plant? Where it is decided as best to have certain engines on the surface, they will, exceptional circumstances apart, be worked by steam; but the scope for electrical applications beyond this at collieries is very great. The underground workings of modern collieries are becoming so extensive, and comprise, as time goes on, such long distances, that to perform all the haulage in the mine from the surface by means of ropes is not within the range of effectiveness and economy. We mention rope haulage because it is extensively used, having its engines above ground, and also because other means of transmission are dealt with elsewhere. A modern colliery deals with considerable loads, and as the ropes represent in themselves a considerable weight, we comparatively soon

reach a limit, and the wear and tear and frictional resistance upon long rope arrangements are very considerable. What we may call supplementary haulage, having its power underground, appears to be a growing necessity, and for such supplementary haulage electrical applications exactly meet the necessities of the case. Compared with other motive powers in mines its conveniences of application are very great, and it is at least as economical as any of them in its use. Long ranges of massive and unyielding pipes are entirely out of place in mines, they are always cumbersome, they will not adapt themselves to the contour of the mine and the bends and turnings, and the inevitable subsidence dislocates the joints if it does not break the pipes, and a simple wire—like Wellington's soldiers in the Peninsula—will go anywhere and do anything, possessing charms of which steam and compressed air in pipes know nothing. Distance is a very serious matter in the case of pipe lines, but really, if need be, the electric wire might extend across the coal area of a county. The special point which has largely hindered electrical applications in mines, and which has exercised the minds of the safe and steady mining engineers and colliery managers, has been that of safety. In the writer's own county of Lancaster the mining is as good and the appliances as excellent as in any mining district of the world, and it is no exaggeration to say that there is no mining district in which more endeavour has been made to promote safety. In all good modern mines everything is being done that reasonably can be done to provide no means of ignition to an explosive mixture, which, however much care may be exercised, is not always avoidable. There has been, putting the matter very mildly, a liability to sparks; and sparks, whether electrical or otherwise, are undesirable in mines. Great progress has been made in electrical improvements, and there has never been any real ground for doubt that the tendency to sparking and other dangers incidental to electricity in its early days would be removed. In mining operations the glaring furnaces of our forefathers have given way to the splendid ventilating machinery which adorns the workings of our collieries without one iota of danger in its operation. The steel mills and the candles of our ancestors, which were incitements to mining disasters, have vanished before the march of the safety lamps of

various types, differing only in their degrees of safety; these accomplishments of far greater triumphs have made it inevitable that before the twentieth century has far advanced electricity in mines will be a safe and effective servant, absolutely under control. Even now the sparking very much depends on the voltage of the system. The higher voltages, which are more economic, and make longer distances effectively obtainable, still have that tendency, and the colliery manager hardens his heart; but voltages equal to anything really required in mining are capable of being applied to mines without any fear of sparking. Then there are other operations beside the haulage in the mine for which electrical application is most effective and convenient. The main ventilation of a colliery, although capable of enormous volumes at a substantial water gauge, does not always of itself suffice, because there may be some special parts of a mine where a considerably higher water gauge is required. It would be most wasteful and costly to deliver say half a million cubic feet of air per minute at a twelve-inch water gauge for the purpose of ensuring a few thousands of cubic feet per minute at that high-water gauge at one or two special points; when probably a water gauge of three inches would suffice, and be infinitely better for the main volume. For this special ventilation what we call auxiliary ventilators are stationed at the requisite points for dealing with these special places, which obtain any volume and any water gauge required. Electricity is the best possible power for such auxiliary ventilating arrangements. Then take the case of water which is "made" in the workings of a mine. If at a higher point than the bottom of the pit shaft, and if there is a falling channel all the way, gravitation will do what is necessary. But the water is often made at a lower point than the bottom of the pit shaft, and power is required to bring it there. We may convey it in water carts and play havoc with the roads; we may use ropes, which are cumbersome; we may apply compressed air if it is located conveniently; but an electric wire transmitting electrical energy possesses virtues peculiar to itself.

As to the application of electricity to coal-cutting machinery, which at this point can only have a casual reference, great success has attended this; and it is not too much to

say that although coal-cutting machines in some instances are worked by compressed air, the general adoption, or even extensive use of coal-cutting machines is only possible by the acceptance of electrical applications. Steam was and is impossible for such a purpose; compressed air cumbersome pipe ranges could not be otherwise than clumsy and ineffective; rope connections offer no remedy for defects and difficulties; and it has remained for electricity to step into the breach and pave the way for the great and successful future of coal-cutting by machinery.

Probably sufficient has been said, without taking up a position in the ranks of unbalanced and unbridled enthusiasts, to show how much really good work there is for electricity as a motive power at collieries; and a writer need not be a prophet, or the son of a prophet, to predict, with reasonable prospect of fulfilment, that each year of the new century will see an increasing application of electricity as a motive power in mines. Nothing can prevent the extensive adoption of this wonderful form of energy as an important feature in the working of all mines worthy of the name in all the mining countries of the world. It will be said that the reader might have been afforded a little more information with regard to electricity itself—not merely what it can do, but what it is, and how it is produced. The writer has purposely avoided this. Even the most eminent amongst us have had to plead ignorance as to what electricity really is, and no doubt it is more easy for a man of eminence to admit insufficiency of knowledge than it is for the possessor of that little knowledge which is a dangerous thing. There is no higher authority in electrical matters than Lord Kelvin, formerly Sir William Thompson. Not very long ago he was being conducted over a very admirable works, noted for the production of excellent electrical machinery, and the foreman who guided his footsteps did not know who his visitor was, but very courteously took the trouble to explain everything that came under notice. At the end of the inspection Lord Kelvin, who, with the true manner of a real gentleman, had followed with interest all that was said, asked his guide in the smoothest manner possible, "What is electricity?" "I cannot tell you," said the foreman. "Neither can I," said Lord Kelvin, and made himself known. What the

greatest electrician in the world admitted his inability to accomplish, the present writer, who is no electrician, will not attempt.

There are works somewhat in abundance now dealing with the subject of electricity especially, and from those much useful and interesting information is obtainable, although they all leave a good deal unexplained. Electricity is a form of energy which can be generated by a steam engine or other power giving motion to the electrical machine known as the dynamo; from this dynamo the electrical energy thus generated by mechanical power passes through a wire to the electrical machine known as the motor, which is practically a dynamo reversed. The motor receives the electrical energy, and by its motion and action upon a pumping, or hauling, or ventilating, or other machine, reconverts the electrical energy into mechanical energy, and performs mechanical work.

There are a few terms in common use with which, no doubt, the general reader is well acquainted, but for the benefit of an occasional one who may not have even that limited amount of information, we venture to mention them in concluding this chapter. The pressure in electricity is represented by the term "electro-motive force," abbreviated into E.M.F. This pressure is measured in "volts," and the current strength or rate of flow in "ampères"; the friction of the electricity is called resistance, being measured in "ohms." The pressure in volts, multiplied by the quantity in ampères, gives a product called volt-ampères, which we call "watts." One watt equals one volt multiplied by one ampère, and seven hundred and forty-six watts are equal to one horse power. One British Board of Trade "unit" of electricity is one thousand watts, and is the amount of electrical energy representing one and a third horse power for an hour. It has been mentioned some little distance back that there is an effectiveness and economy in high voltages. The resistance to the electric flow, and the consequent loss, is greater with small wires than large ones, and with long wires than short ones. The cost of the copper wire will also vary inversely as the square of the voltage. Electric current is attainable as high as twenty thousand volts, which possesses special advantages in the avoidance of loss and in the diminution of the expense of

copper wire. But, as we have already stated, currents of high tension are dangerous; the circuit becoming broken, the current would pass across the break, and produce sparking. If such a current passed through the human body the result would be fatal.

CHAPTER III.

STEAM BOILERS FOR COLLIERY USE.

HOWEVER interesting it may be to do so, it is not proposed in this work to enter into matters of history, except in so far as comparison between modern appliances and their early prototypes may be useful in making quite clear the nature and purpose of the improvements which have been effected.

With regard to boilers, therefore, although the historical side of the subject is full of interest, it will perhaps be more useful to confine our attention to the more modern types of steam generators, more particularly that well-tried and reliable servant, the Lancashire boiler.

Nor is it the author's intention to say much with reference to the use of steam boilers underground, although they are still to be found here and there in the various mining districts.

We all understand that a steam engine in the mine, with a steam boiler adjoining, will show a high useful effect. We also all understand that the underground boiler can be fully utilised, so far as the heat is concerned, because it assists in the rarefaction of the upcast shaft. But steam boilers underground were not right and proper, even years ago, and in the twentieth century ought to be obsolete. They shall be obsolete so far as these pages are concerned. Steam for colliery use should be generated on the surface. The boiler which has established itself most firmly for colliery use is the Lancashire boiler, so called, no doubt, because it was first applied in Lancashire, England. It comprises a cylindrical barrel with flat ends, and two internal flues, not always cylindrical throughout, passing through it from end to end. It has increased in diameter, and the size now in general use is eight feet; the length has never varied very much, except by the exigences of location, and a fairly

convenient and effective length is thirty feet. A Lancashire boiler of these dimensions can be made strong enough to work quite safely at the highest pressure at which steam can be conveniently used—namely, about 250 lbs. per square inch absolute. Such a boiler, with a consumption of two pounds of coal per horse power per hour, can generate steam equal to a continuous horse power of 500. The improvement of late years in steam boiler design and construction has been very great. The improvement in design, with a view to more effective steam generation, has of course been in consequence of the increased ability of our boiler engineers. The improved construction has been due almost entirely to the application of machinery in boiler construction, together, of course, with the improved quality of the materials used. In the old days practically no provision was made for the expansion by heat and contraction by cold, and the result was rapid distortion, which had a serious weakening influence. No endeavour was made to bend or flange the plates in anything but the crudest fashion, and true curves were conspicuous by their absence. The plates were far too numerous, and brought together in the most indifferent fashion, and the securing of the joints was a rude arrangement which injured the plates in making the holes, and ensured no uniformity of strain in filling the holes. The flat ends, known to be a source of weakness, did not receive that attention which places capable of weakness ought to receive.

All this is changed; provision is made for expansion and contraction, and a lengthening or shortening is practicable without injury. The plates are much less numerous, with a proportionate reduction of the joints. Each ring and each end can be made in one piece. All the bending is done by mechanical means, and every plate in the barrel is a true circle. The same remark applies to the portions that have to be flanged. The end plates are bored to receive the boiler tubes; each plate in the barrel is planed on the edges; the joints are made by having all the holes drilled, so as to ensure a true circular hole and avoid injury to the plates; the plates are secured to each other by mechanical action, which gives us almost perfection in the uniformity of strain on each rivet.

These general remarks show briefly the great progress in

boiler engineering, which now takes its position on an equality with the engineering of the engines themselves. Figs. 1, 2, 3, 4, and 5 (*see sheets* 1 *and* 2, *between pages* 28 *and* 29) show three Lancashire steam boilers in position, resting upon and surrounded by the seating of brickwork. The figures give a good idea of the advantages which the boiler possesses in the matter of heating surface as compared with its predecessors. We have already mentioned that a good steam boiler must have sufficient and effective heating surface to absorb the heat which is generated. The heating surface is the surface of the boiler plates on which the heat can act. In the Lancashire boiler we have the interior surface of the flues which run through the boiler, not all equally effective, because it is found in practice, and will easily be understood, that the heat will more readily rise and act on the upper half of the surface than it will fall and act upon the lower half of the surface. In the same way with the firebox of a locomotive: each square foot of the crown is worth at least two square feet of the vertical sides. The heating surface of the Lancashire boiler also comprises that portion of the side flues and that portion of the bottom flue exposed to the action of the heat. There is, further, some amount of heating surface at the back end, where the hot gases pass into the side flues; and yet again the heating surface of the Lancashire boiler is increased and improved by the well-known Galloway taper tubes, which are placed in the boiler flues somewhat out of the vertical, and placed so as to alternately incline to the right and to the left. The total heating surface of the Lancashire steam boiler of the orthodox modern dimensions is about one thousand square feet, and it is not easy to see how that amount is to be much increased. This limited heating surface is a defect of the Lancashire boiler, but for colliery use it has many advantages. Provided that the material and the design and the construction are good—there is nothing to prevent either,—and that the working of the boiler is conducted with reasonable care, the Lancashire boiler is absolutely safe. Further, provided that the water used is not such as to defeat the action by deposit of sediment and scale, or calculated to eat the plates away, neither of which should be allowed, a Lancashire boiler will give a good account of itself for half a century, and will cost comparatively little for repairs. It

occupies more room than some more recent boilers for the same power, but this is not material, because pits are not often sunk and colliery plant located where land is of great value. With regard to the seating of a Lancashire boiler, some prefer a little inclination to the front, others prefer a little inclination to the back. The boiler should rest upon firebrick blocks; the flues should be cased with firebricks—that is to say, the outer flues; and the side flues should be so arranged that the hot gases cannot act above the water level. The hot gases generated on the firegrates at the front end of the boiler pass along the internal flues, and at the back end are diverted under the boiler and pass to the front, where they split, and come along the side flues, and afterwards proceed along the main flue to the chimney. It is in this main flue that the well-known Green's economiser is situated, for the purpose of absorbing into the feed water some of the heat which has not been taken up by the heating surface of the boiler itself.

In the construction of a steam boiler steel is almost universally used, and there ought to be no difficulty in obtaining material having a tensile strength of thirty tons per square inch, together with the needful ductility, which may be anything up to 25 per cent. In good boiler making, we take a strip from every plate for the purpose of knowing the actual strength and ductility of every plate, and of securing for all the plates of any one boiler an approximate uniformity. It would never do to have plates in the same boiler with much variation; it would be as fatal as weak links in a chain. The construction always gives us less strength than the solid plates, because joints are weaker than the plates, and our endeavour is to diminish this weakening as much as possible. At one time it was proposed to use oval rivets, as shown in fig. 6. The pull upon a boiler is greater crosswise than lengthwise, and the oval rivet was intended to

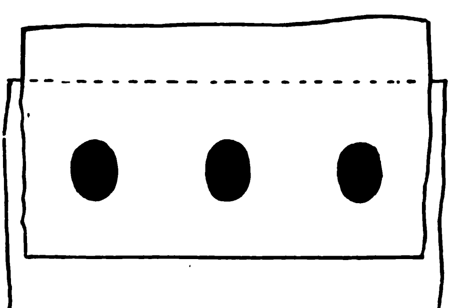


FIG. 6.

adapt itself to this inequality. Then it was proposed to thicken the plates at the joints, as shown in fig. 7, which was

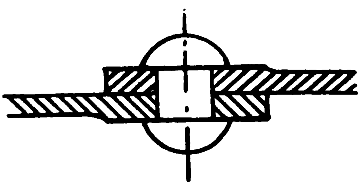


FIG. 7.

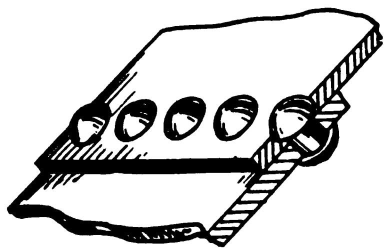


FIG. 8.

intended to replace the ordinary joint as shown at 8, 9, and 10. Neither of these amounted to very much, and the benefits were

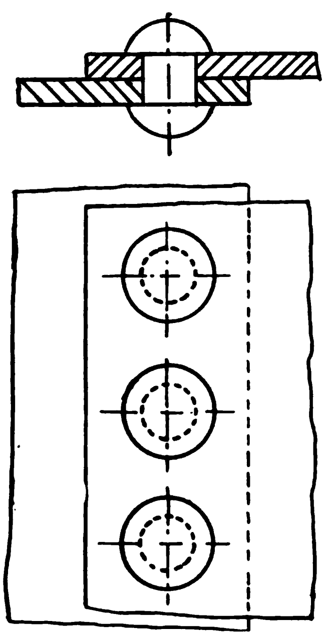


FIG. 9.

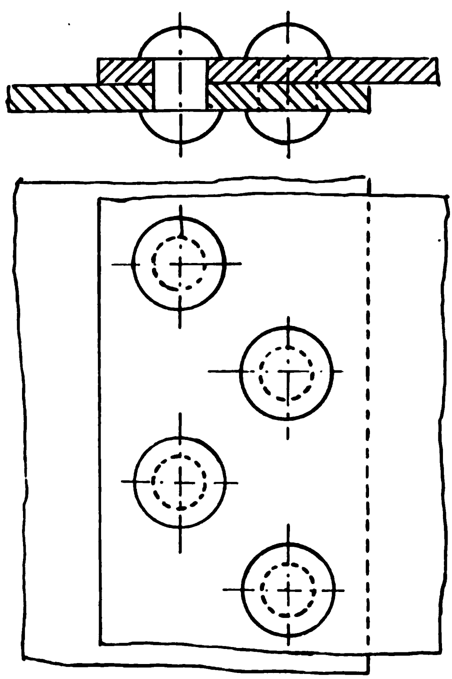


FIG. 10.

not as great as the trouble. The single-riveted joint is shown by fig. 9, and a double-riveted joint is given in fig. 10.

The latter is stronger than the former, and is now almost universally used in boiler construction. The weak direction of the boiler is diametrical, and the weak joint, therefore, is the horizontal. The greatest improvement, therefore, has been in diminishing the number of horizontal joints, by having only one plate and one joint in each ring. Fig. 11 shows a butt joint, single riveted. There was a very interesting deliverance some years ago as to the leading proportions of riveted joints. In the old single-riveted days, a rule easily remembered was that the rivet should have a diameter equal to twice the thickness of the plate; the pitch of the rivets and the lap of one plate on another should be each three times the diameter of the rivet. But we have said that the joints of modern times are practically all double riveted; and the following proportions have been given. In double-riveted lap joints there are two kinds, namely zigzag, as shown on fig. 10 (*see page* 31), and chain, by which we mean that the rivets of the two rows are opposite to each other, fig. 12. The latter arrangement is the stronger, and we therefore deal with it only. The diameter of the rivet equals twice the thickness of the plate; the lap of one plate upon another equals five and a half diameters of the rivet; the distance between the two lines of rivets, centre to centre,

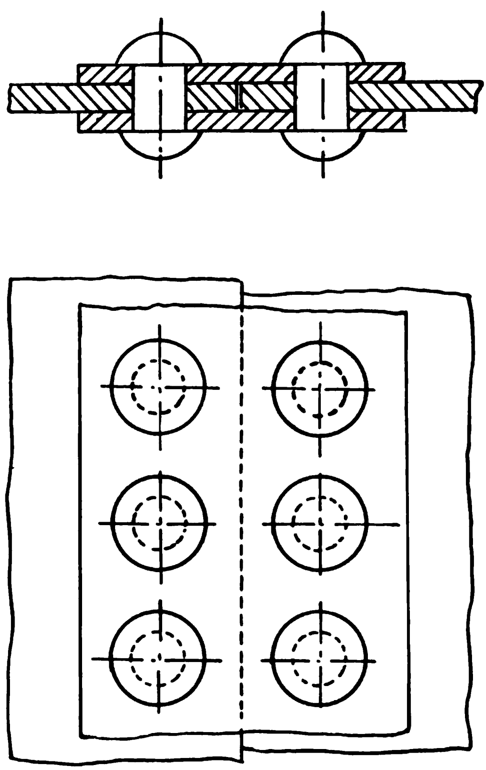


Fig. 11.

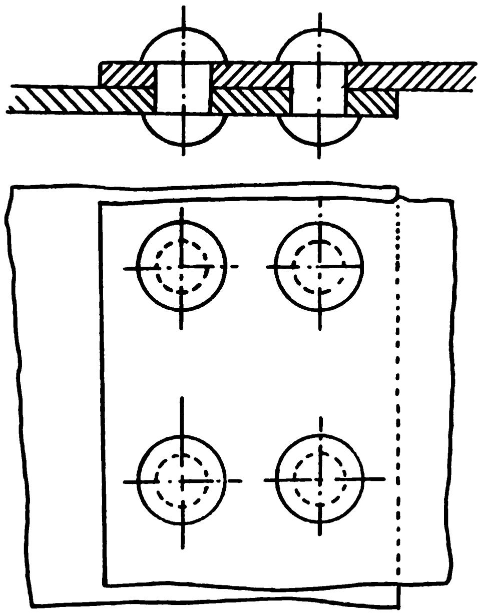


FIG. 12.

equal two and a half diameters of the rivet; and the pitch of the rivets—that is to say, the distance along either line from the centre of one rivet to the centre of the next —equals four and a half times the diameter of the rivet. In this same deliverance, recognising the inequality in strength of the two directions of the boiler, diagonal joints running round the boiler and along the boiler at an angle of forty-five degrees were proposed as increasing the strength of the boiler in the ratio of four to five. These diagonal joints have not come into use. With regard to the internal flues which form an essential part of the Lancashire boiler, early experience was that they collapsed, and they were strengthened at each ring seam, as shown in fig. 13. The strengthening was provided for and the collapsing ceased; but

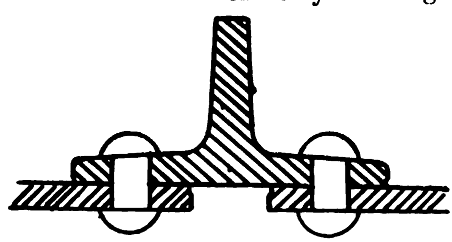


FIG. 13.

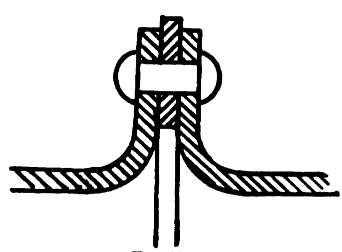


FIG. 14.

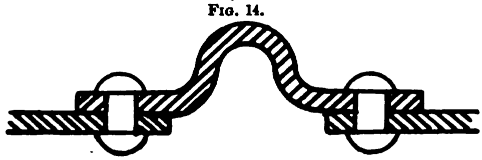


FIG. 15.

another difficulty arose by reason of expansion and contraction; the methods shown in figs. 14 and 15 (*see page* 33) were subsequently applied, and the former, known as Adamson's joint, is now very generally adopted. The flat ends of the Lancashire boiler may be secured to the barrel as shown in fig. 17, or as shown

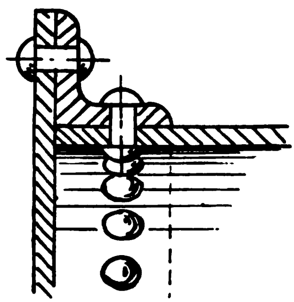


FIG. 16.

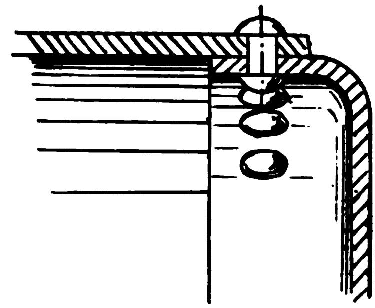


FIG. 17.

in fig. 16, either of which forms a convenient connection; the former is more elastic, and the latter presents a larger available area at the front for boiler fittings. The longitudinal bolt stays running from end to end, with a nut within and without each end plate, are now rarely used, the strengthening of the end plates being provided for by the gusset stays, which are fairly well represented on figs. 18, 19, and 20. (*See page* 36.) A gusset stay is a plate similar to the plates of the boiler and fitted to the barrel and the end, the attachment being effected by angle iron. Fig. 1 (*see sheet* 1, *between pages* 28 *and* 29) is intended to give a section longitudinally of the boiler, giving an idea of the arrangement of the ring seams of flues, the plates of the barrel fitting upon each other and the mountings or branches to which the various boiler fittings have to be attached. Fig. 21 (*see page* 37) represents a corrugated flue intended to afford expansion and contraction where they are greatest—namely, at the furnace—and also to increase the heating surface. Fig. 22 (*see page* 37) illustrates the Galloway tubes, which have been touched upon a little way back. There is no doubt that this is a really important equipment of a boiler. It increases the amount of heating surface, and this increase is heating surface of the most effective kind, because the hot gases actually strike these tubes, and by being obstructed are made to act more effectively upon the surface of the internal flues. But probably the greatest benefit they confer is the increased circula-

tion in the boiler. A boiler with defective circulation cannot be a good steam generator, and the Galloway tubes produce a circulation; the water as it is heated flows up these tubes, and there is a corresponding descent of the water outside of the internal flues, and in this way a good circulation is maintained.

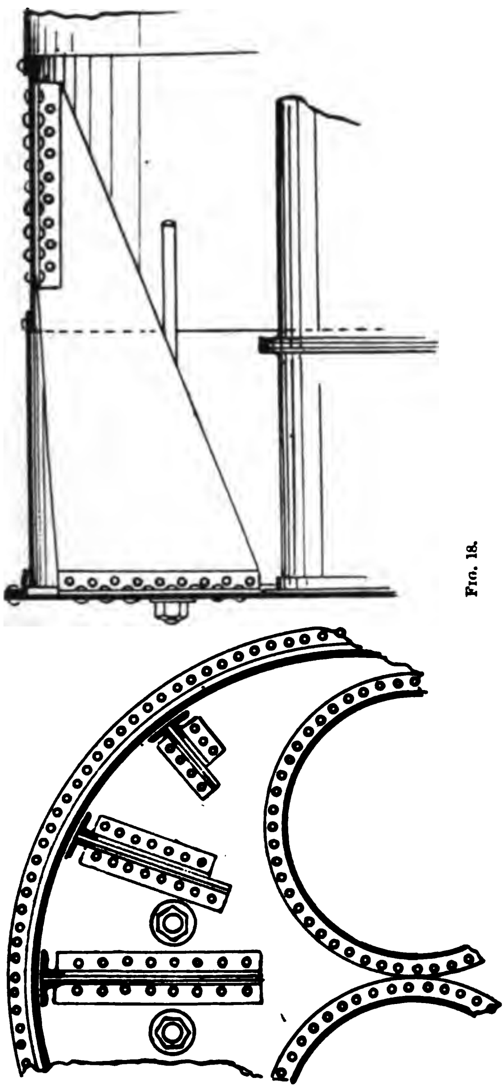


FIG. 18.

A very important matter in connection with a steam boiler is the equipment, which comprises all the fittings by which the steam generator becomes a workable piece of mechanism. Not the least prominent is the safety valve, whose function is to determine the pressure above which the steam shall not rise—that is to say, suppose the boiler is intended to work at a pressure of 100 pounds on the square inch, the safety valve will allow the pressure to rise to that point but not beyond, because the valve will open and allow the steam to blow off into the atmosphere. It is quite evident that such an appliance is an absolute necessity, not only as fixing the pressure at which we wish to work, but because if such an appliance was not at our command

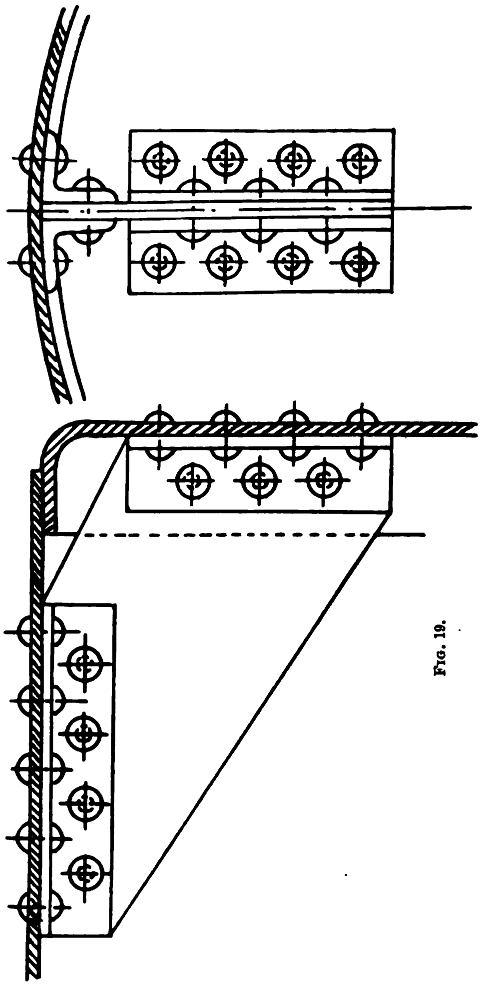


Fig. 19.

the pressure at which the boiler might, and probably would, rise indefinitely, and disaster would be the result. A very popular boiler safety valve for a long time was the mushroom or single beat valve, with spindle or wings, and having a lever and weight attachment, fig. 23. (*See page* 38.) There are not many of these in use now, and there ought to be none. The term safety is wrongly applied to it. The spindle and the wings are liable to stick by the tilting of the valve, and the moment that the lever changes its horizontal position this tilting and wedging becomes possible. They never operate accurately, and whilst they will allow the steam to rise above the determined pressure, they will also allow the steam to continue blowing off after the pressure has fallen below the determined point.

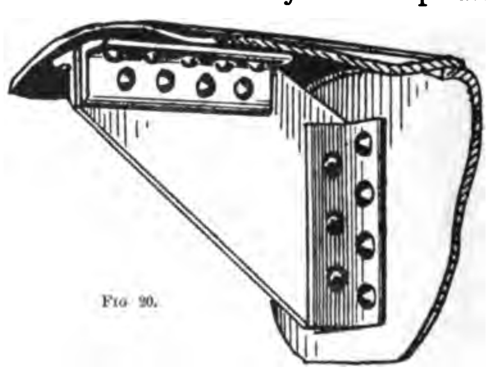


Fig. 20.

The arrangement used to be that the proportions of the safety valve lever—namely, from centre of the fulcrum to centre of weight, and from centre of fulcrum to centre of valve—should be the proportion of the area of the valve in square inches to one, and the weight at the end of the lever should be the working pressure in pounds per square inch. Suppose we had a boiler to work at 100 pounds pressure, and the safety valve was four inches in diameter, equals twelve and a half square inches area, this weight at the end of the lever would be 100 pounds, and the proportions of the lever would be twelve and a half to one. This so-called safety valve was replaced by the well-known dead-weight safety valve, of which there are many types. This principle is fairly well represented in figs. 24 and 25.

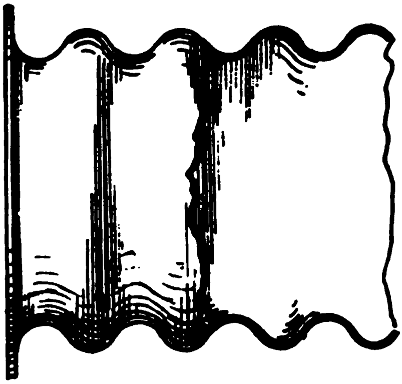


FIG. 21.

(*See pages* 38 *and* 39.) The valve is a portion of a sphere, without spindle or wings, and always fits right whatever its position; it cannot tilt, and therefore cannot wedge. There is no lever, and the weights surround the valve, the centre of gravity being below the seating. The total weight upon the valve has to equal the working pressure in pounds per square inch multiplied by the area of the valve in square inches. That is to say, a boiler working at 100 lbs. pressure with a four-inch safety valve would have to be weighted with 100 multiplied by 12½, equals 1250 lbs. This dead-weight safety valve is an excellent one, and works correctly. A really

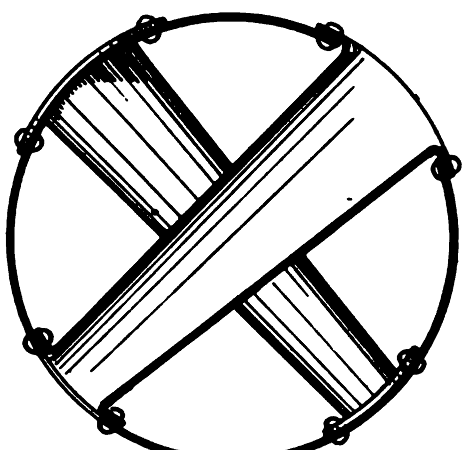


FIG. 22.

good type will start blowing off immediately the working pressure is exceeded, and will close immediately the pressure falls to the working point. It is absolutely safe, and as nearly as

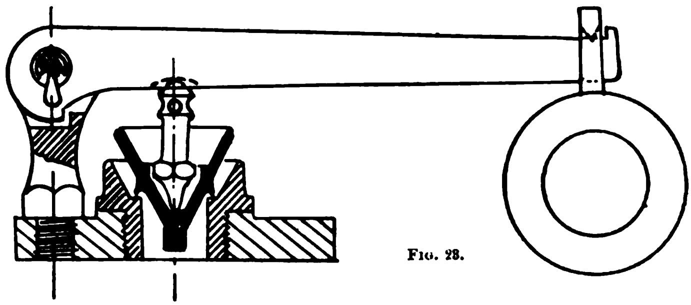


FIG. 23.

possible correct in action. It will be seen that this dead-weight safety valve only prevents excess of pressure, and that ought to be all that a safety valve should have to do; but by some cause the water level in the boiler may be allowed to fall too low, endangering the safety of the boiler by laying bare the crown of the flues to the action of the heat. As a safeguard in this case, what we call a low-water safety valve is applied, which, when the water level falls too low, opens, and the steam blows away, whatever the pressure. The principle of this low-water safety valve is well shown in the general boiler arrangement (*see fig.* 29, *sheet* 3, *between pages* 44 *and* 45) and in fig. 26. (*See page* 40.)

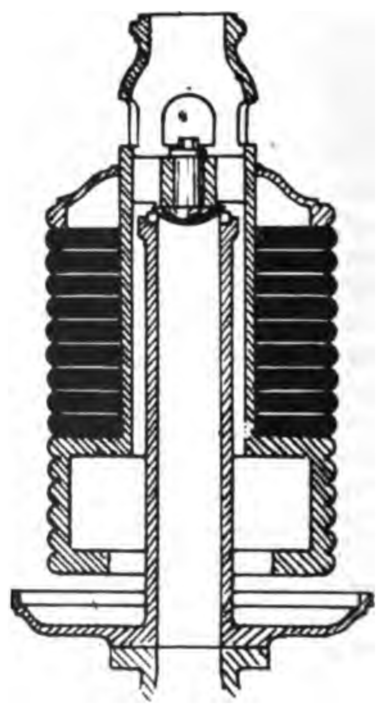


FIG. 24.

The branches placed upon boilers were formerly all cast iron, but they are not now used much, and should not be used at all. They will not yield to the shape of the boiler; they are liable to break in the attachment; and they are difficult to caulk—that is to say, to make tight on the boiler. Steel

mountings are much better; they are stronger, lighter, more pliable, and lend themselves to caulking. At one time steam domes were inseparable from boilers, and were intended to serve the useful purpose of enabling the steam to be taken off sufficiently high to be dry. But they are not common now; they are inconvenient, and they weaken a boiler. The strongest argument for dispensing with them is that we can accomplish what they were intended for much better in another way. The Lancashire boiler possesses in itself a substantial amount of steam storage, but we can do with more; and a general and very good method now is to have a receiver of considerable dimensions, say three feet in diameter, running across a range of boilers. The steam pipes for conveying the steam to the engines can be attached to the receiver at any point, and no doubt the upper portion of the receiver will be preferred, as furnishing the driest steam supply, because the water in the steam will hardly rise to such a height. There will, of course, be separate communication to this receiver on the part of each boiler in the range. When the engines to be driven are close to the boilers, the only provision, perhaps, is that there should be a bend in the length to afford a convenient means of dealing with expansion and contraction. This is, of course, much more necessary when the distance between the engines and the boilers is considerable. It is almost impossible to prevent

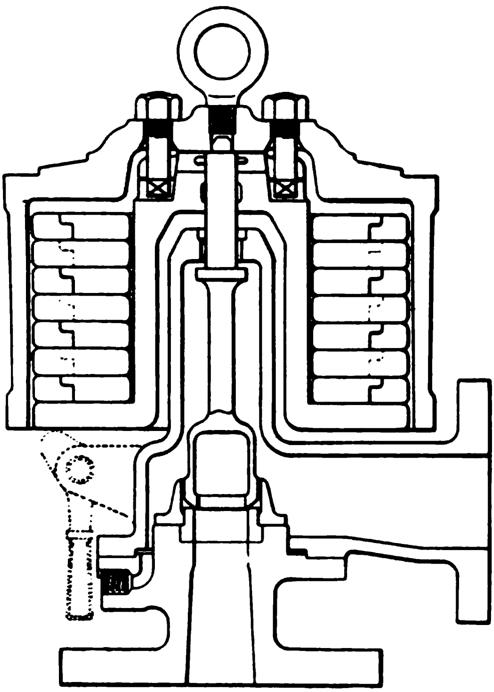


FIG. 25.
HOPKINSON'S "IPSED" DEAD-WEIGHT SAFETY VALVE.

the formation of some water in the passing of the steam along the pipes, and a simple method of preventing this water reaching the engines is to place a separator in the steam range. The obstruction and the diversion effectively

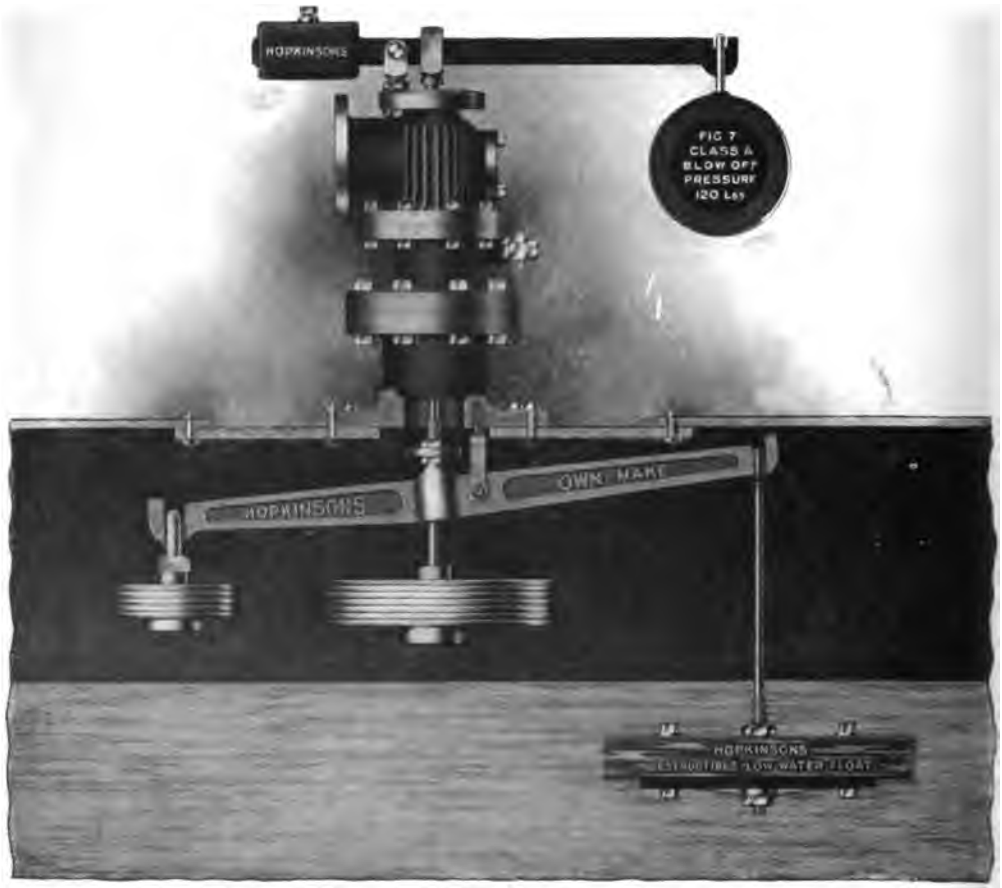


Fig. 26.

Hopkinson's High-Steam and Low-Water Safety Valve.

accomplish what is necessary. Taking each boiler separately provision has to be made for the conveyance of the steam in as dry a condition as possible. The Lancashire boiler is a good generator, and calculated to generate dry steam; but this cannot always be relied upon, because a sudden demand for steam disorganises the generation, and it happens

that impurities in the steam are responsible for defective working. Whatever the causes may be, what we call "priming" is a complaint attaching to nearly all boilers more or less; it signifies that the water is mingling with the steam, and endeavouring to leave the boiler with the steam. Bad water will cause priming. Excessive firing will cause priming. Insufficient steam power or steam capacity will produce priming. In a good Lancashire boiler the steam pipe within the boiler is placed horizontally, as high up as possible, and is about six feet long. The only communication between the boiler and this pipe is by means of small perforations, a quarter of an inch diameter, in the upper part of the pipe; the ends of the pipe are closed. This arrangement is spoken of as anti-priming, and really performs that operation very well.

The appliances by which feed water is admitted to the boiler always require careful consideration. The old method was to deliver cold water through an open-ended vertical pipe, and generally this pipe delivered on to the hottest part of the boiler. No doubt many a boiler has been ruined in consequence, and in every case the repairs would be almost continuous. We ought to remember that a steam boiler is a hot vessel, and the feed water delivered into it should be, as nearly as may be, as hot as the contents of the boiler itself. We accomplish this in various ways. If our steam engine is condensing we can always rely on the hot products of condensation; if the engine is not condensing we heat feed water in another way. A simple plan has been to use an old boiler, and passing the exhaust steam through it one way and the feed water through it the other way, the heat of the one was imparted to the other but with all its impurities thick upon it. To obviate this, specially arranged heaters have been constructed, either circular or rectangular, after the manner of surface condensers. These vessels have a number of tubes a few inches in diameter running from end to end; the exhaust steam passes through these vessels outside these tubes, cold water is circulated within the tubes and this cold water becomes heated. Probably the most perfect method of imparting heat to the feed water is the Green's economiser, which is placed in the main flue between the range of boilers and the chimney; the feed water passing through the pipes of the economiser is heated by the hot gases in the

main flue. (*See fig.* 43, *page* 80, *and figs.* 44 *and* 45, *sheet* 4, *between pages* 80 *and* 81.) Assuming this feed water to be heated, it is passed into the boiler through a horizontal pipe some six feet or more in length. This pipe is placed a few inches below the water level, and the water makes its way out through small perforations, so that the water is in the best possible form and condition—namely, hot spray. All good feed arrangements are now of the back-pressure type—that is to say, the pressure within the boiler is always endeavouring to close the valve. It is a good plan to attach a scum arrangement to a boiler. In many cases the water used is chemically suitable—that is to say, there is no corrosive action set up, but matter is held in mechanical suspension. As steam is being generated these particles of impure matter, being surrounded by bubbles of steam, are ballooned to the water level. This matter having reached the water level floats about as scum. It is quite evident that this substance is not desirable in cylinders, and the scum appliance, which is simply an open-topped trough, enables the steam to blow the scum out. It will be readily understood that there is a proper water level at which the water should be kept to enable the boilers to work to the best advantage. No boiler will work well when the water level has an extensive variation. If the boilers are supplying engines working continuously the matter is not difficult, and the feed arrangement can be adjusted so as to maintain a constant level. But colliery boilers are not used exclusively to supply continuous working engines, and indeed a good deal of the supply is very intermittent. In such a case a pointer shows the proper level, and the boiler attendant has to see that the water in his gauge glasses approximately agrees with the pointer. These water gauges are a great improvement on the old float mechanisms, which were liable to stick, and could hardly be called safe. The gauge glasses answer well, although occasionally they burst; but even that can be counteracted by a simple appliance which closes the communication when the glass breaks.

We have to provide in boilers for admission for the purpose of cleaning and inspection and repairs, and for this purpose a mudhole is placed at the front end near the bottom, figure 27, and a manhole on the top. These holes being large enough

to allow the passage of a man, exercise a serious weakening influence, which has to be counteracted by sufficiently strong rings round the opening. We have also to provide for emptying

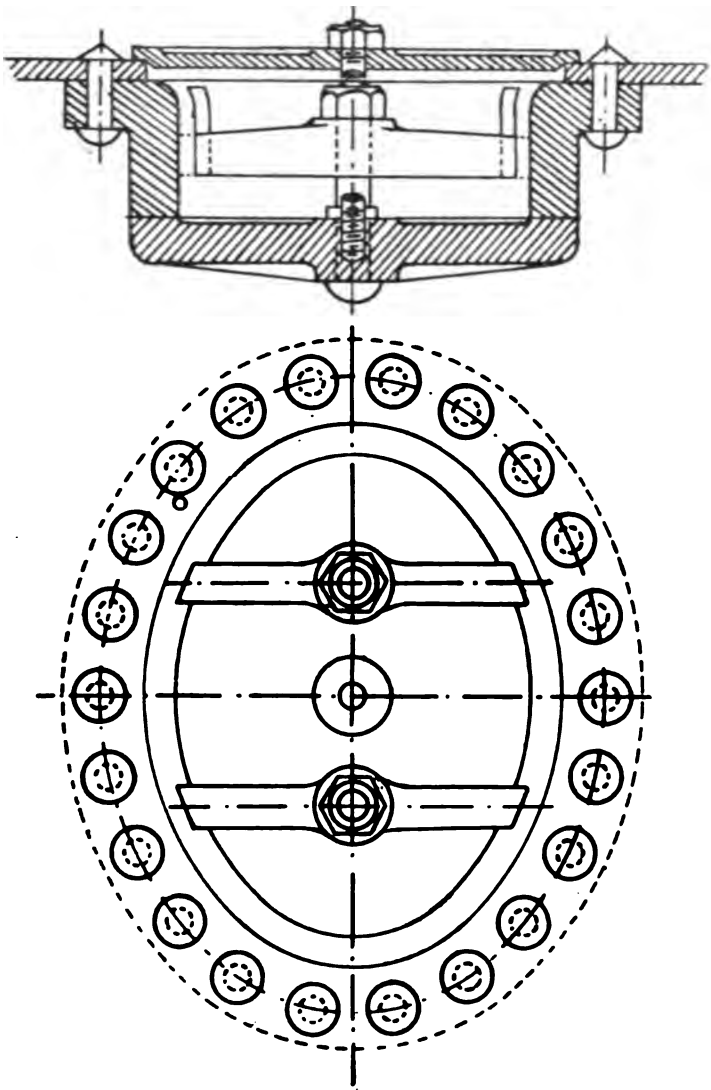


FIG. 27.

a boiler, and this is provided for by a connection at the bottom known as the blow-off arrangement. A fairly good boiler design, as shown on fig. 28 on page 44 and fig. 29 (*see sheet* 3, *between pages*

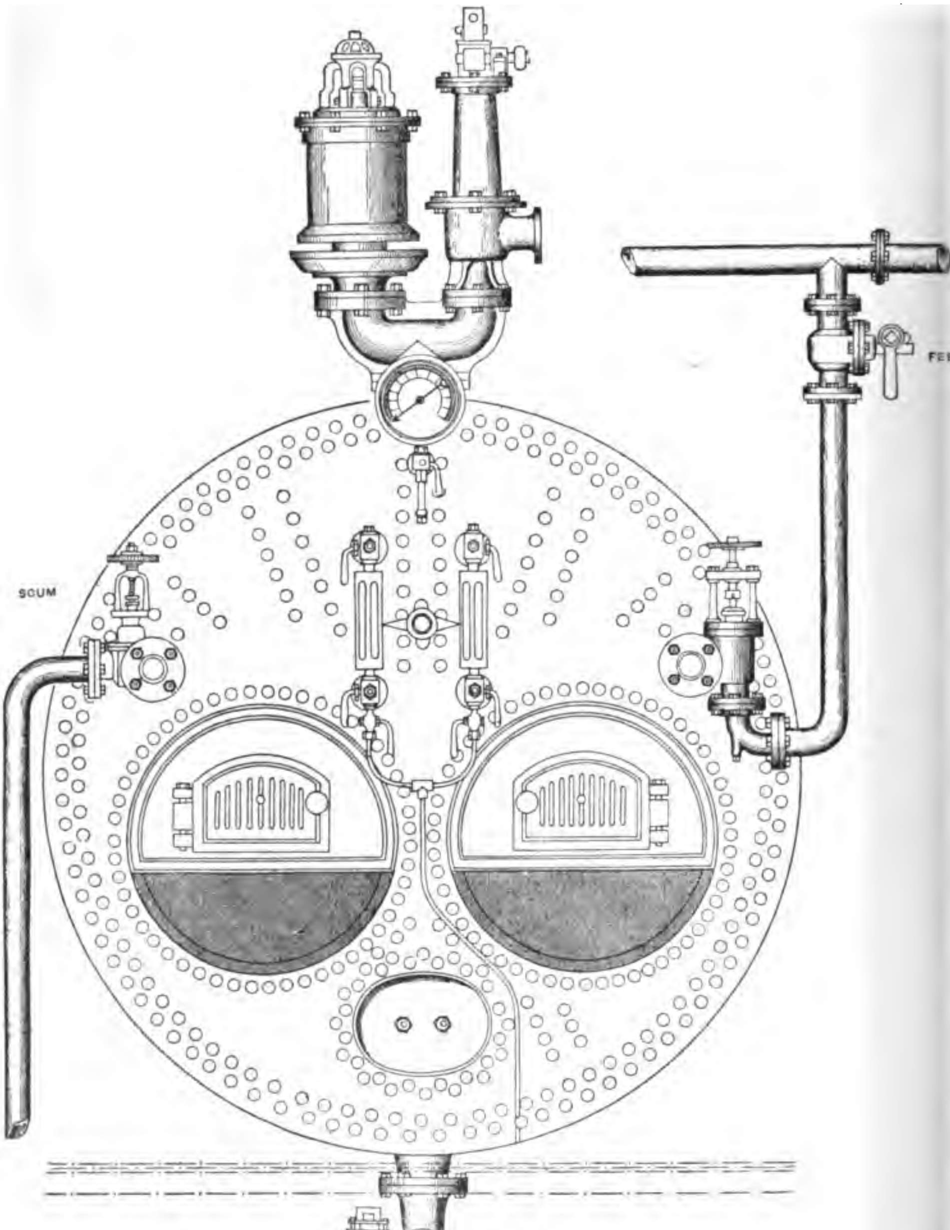
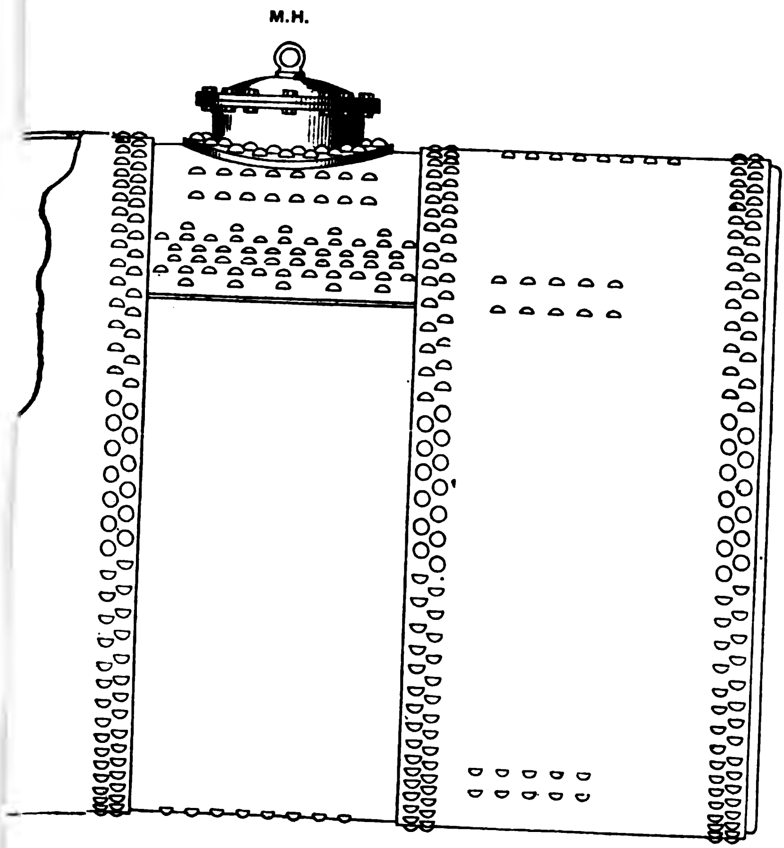


Fig. 28.
Front of Lancashire Boiler with Hopkinson's Fittings.



TINGS.

essure Safety Valve.

off Pipe.

44 *and* 45), represents the feed, the scum, and the pressure gauge upon the front, together with the mudhole; the blow-off appliance is placed under the boiler near the front; the other manhole, together with the safety valves and the steam junction, find location on the top of the boiler.

The steam gauge, which is a familiar and valuable fitting, is constructed in various ways, but the object in all cases is the same. We want to be able to see at a glance what the pressure is within the boiler. The safety valve only informs us when the fixed working pressure has been reached, whereas the steam gauge gives us the pressure whatever it is. A mercurial pressure gauge records the pressure by a column of mercury, and is the most accurate, but not convenient. A column of mercury two inches high practically represents one pound per square inch of pressure, and as steam boilers are now worked at as much as 200 lbs. pressure, a mercurial column four hundred inches or thirty-three feet high is impossible. The well-known Bourdon steam pressure gauge is about as good as any in the market, and has had the advantage of being combined with excellent mechanism. The principle is very interesting, and not difficult to understand. If we take a straight tube, truly circular in cross section, and bend that tube, the cross section will disappear proportionately with the curvature. Then, if we apply pressure within this bent tube, the tubes will tend to straighten, and the circular cross section will tend to re-appear. Upon this ingenious principle has been built up the very successful Bourdon steam gauge.

There is an important fitting of a steam boiler which is entitled to a few words of mention—namely, that connected with what we call the furnace, which comprises the firegrate for the deposit of the fuel, and the firedoor forming the communication. We are assuming—without being specially in favour of the arrangement—a system of hand-firing. The front portion of the furnace, for about a foot in width, is what we call the dead-plate. It is solid, and has no perforations, the original intention being that the coal should be allowed to do the early portion of its combustion on this dead-plate, and then be pushed forward. As a matter of fact, it constitutes a convenient front end of the furnace, without really

being a portion of the grate area. In a Lancashire steam boiler there is, of course, a furnace in each of the two internal flues, the one being a facsimile of the other, and providing a total grate area of about forty square feet, or twenty square feet each. The diameter of these flues is about three feet three inches, showing that the length of firegrate required is rather more than six feet. The usual practice is to place a firebrick bridge across the flue at the far end of the firegrate, to throw the flame against the upper surface of the flue. Then comes the arrangement for air supply, which, in a well-conducted steam boiler, should chiefly be upwards between the bars; but for a green fire, which is inevitable with hand-firing, the supply of air necessary at the moment could not pass through between the bars. The volume of air required for combustion is very great, and may be anything from 150 to 300 cubic feet for each pound of coal; and for the Lancashire boiler, which we have taken as a standard, will mean anything from 150,000 to 300,000 cubic feet per hour. We have said that a green fire requires more air than a red fire, and in the firedoor there should be a circular or rectangular sliding grid to regulate the opening for air supply. In the old days steam boilers were very poorly protected, but as colliery civilisation has advanced boiler-houses have been provided and they are assuredly worth their cost, not only in comfort to the attendants but in actual economy. In addition to the protection of the boiler-house, the portion of the boiler which rises above the seating should have a coating of a few inches thick of good non-conducting matter, of which there is no scarcity. Slag, in a special form, answers the purpose well. What we want is to keep the heat of the boiler in the boiler. The front end is difficult to protect, and coating it would not be easy.

Three Lancashire boilers adjoining each other, and resting on their seatings, are shown on figs. 1, 2, 3, 4, and 5. (*See sheets* 1 *and* 2 *between pages* 28 *and* 29.) The distance from centre to centre of the boilers will be about three feet greater than the diameter of each boiler, thus providing for fourteen or fifteen inches of brickwork and two side flues of about nine to twelve inches wide each. The flue arrangements in the seating should be such that admission for inspection and for cleaning is not inconvenient. Dust is liable to accumulate, and if not

removed periodically not only do the boiler plates become coated, and the passage of heat obstructed, but the flues may become choked. A boiler cannot become a good steam generator unless the plates are kept clean without and within. Usually the two side flues have each a damper arrangement, and they communicate with the main flue leading to the chimney.

An important feature in connection with a steam boiler plant is the chimney, and the writer is not sure that it would not have been well for colliery plant if some of the difficulties attaching to draught for locomotive and marine boilers had associated themselves with stationary boilers. A chimney is a substantial structure, and may be made a handsome feature in the landscape, but it is hardly economic; its effectiveness depends upon the internal temperature, and the higher that internal temperature the greater the waste of heat. In the locomotive we produce the draught by a steam or exhaust blast, and for the marine boiler we produce our draught by what we call the forced method. The chimney has the very tempting advantage of simplicity, and to a very large extent holds the field for colliery boilers. A good deal of genius and ingenuity has been exercised in designing the tops of chimneys; but it is not at all clear that these ornamental endeavours serve any useful purpose, or are even necessary for appearance' sake. A well-built circular chimney, having an external batter of about three-quarters of an inch to a yard, with a bell-mouthed top, is good enough in appearance for anything. The internal construction may vary, and probably the best arrangement is to have an inner chimney of firebrick within the main structure, and clear of it, and running to something like half the height. Formerly the internal diameter of a chimney at the top was much less than the internal diameter at the bottom, and the smoke was ejected like the jet of a fountain. To avoid waste of energy, the delivery at the top of the chimney should be easy, and it is proper design to make the top internally as large in area as the bottom internally. It is quite true that there will be some cooling in the way, and therefore the volume discharged is less than the volume received, but, as has just been stated, easy delivery is economic. As to the size of a chimney, it would appear to be a fairly good practical rule to make the internal cross-sectional area equal to the total area

of all the boiler internal flues connected with the chimney. We are not overlooking the fact that nothing like the effective cross-sectional area of each internal flue is available for the admission of air; but we are also bearing in mind that not only the volume of air entering the flues, but the volume of gas generated in the furnace enters the chimney. Proceeding on these lines, the diameters internally of round chimneys would be about as follows:—For one boiler, a chimney five feet internal diameter; two boilers, six and a half feet; three boilers, eight feet; four boilers, nine feet; five boilers, ten feet; six boilers, eleven feet; seven boilers, twelve feet; eight boilers, thirteen feet; nine boilers, thirteen and a half feet; ten boilers, fourteen and a half feet; and so on, the figures being of course approximate. Then comes the height of the chimney, and the best local authorities render some assistance by stipulating that no boiler chimney shall be less in height than thirty yards. For the cleanliness of the community the rule is a good one. We have higher chimneys for larger ranges of boilers, because as the number of boilers increases the resistances to draught increase, and additional height is given to the chimney to give a better draught. It has been determined experimentally that chimney draught is most effective when the internal absolute temperature of the chimney averages twice the external absolute temperature, which virtually means an internal temperature of about 600 degrees ordinary. Under these conditions a chimney thirty yards in height would probably give us 0·6 of an inch of water gauge, and each additional five yards of height will increase the water gauge 0·1 of an inch. Such a height as thirty yards, and such a water gauge of 0·6 of an inch, would probably answer well enough for a couple of standard Lancashire boilers thirty feet long and eight feet diameter. If we added five yards in height for each additional boiler, three boilers would have a water gauge of 0·7 of an inch; six boilers would have a water gauge of 1·4 inches; nine boilers, 2·1 inches; twelve boilers, 2·8 inches; the chimney heights being respectively three boilers, thirty-five yards; six boilers, seventy yards; nine boilers, one hundred and five yards; twelve boilers, one hundred and forty yards. It may be thought that some of these dimensions are liberal, but it must be remembered that the Lancashire boiler of to-day is a more substantial appliance in matters of dimension than the Lancashire boiler of years gone by.

The problem of smoke prevention has not altogether been solved so far as practical operations are concerned, and collieries are perhaps less harassed in the matter of prosecutions in this matter than other industries whose location is more under the vigilant eye of the city and town authorities. There is no doubt too little of smoke prevention, and one is led to the belief that in many cases the boiler plant is insufficient. If a steam boiler is forced beyond its normal capabilities, more coal is placed in its furnaces than can be effectively consumed, and smoke is inevitable. We are perhaps too ready to say that black smoke from chimneys is waste, and that invisible gases represent economy. Black smoke is waste; but a chimney may be more wasteful and be pouring out matter even more unhealthful when no smoke is visible. Still the Acts of Parliament deal with black smoke, and this is really preventable to such a degree with ordinary care, that it ought to be to a very large degree prevented. Mechanical stoking, when the system is right, is a smoke preventer, because the action of the furnace is continuous and uniform, the fire is always in the same condition, the gases from the green coal at the front passing over the red fire at the back, and in this way a chimney really attracts no injurious attention. But even without mechanical stokers no chimney needs to send forth great volumes of black smoke if our boiler capacity is sufficient, if we use reasonably good fuel, and if we have a moderately good fireman who understands what a boiler is, and that for effective work the firing should be frequent. Each time fresh fuel is put on a larger volume of air should be admitted and gradually diminished as the fire burns up. We are not entering into any argument here for or against boiler firemen being certificated, but we do think that the majority of boiler firemen know much less about working a boiler effectively than they ought to do. Better firemen would probably be obtainable with somewhat better pay, and whilst a good boiler fireman will avoid smoke, reduce the wear and tear upon his boiler to a minimum, and generate the maximum amount of steam from a given weight of coal, a bad boiler fireman will accomplish the reverse of all this. Better wages for better men appears to the writer to be the proper thing.

A good deal has been said about steam boiler explosions, but with the advance in boiler engineering a change has come over

the scene, and boiler explosions are really very rare; they ought not to happen at all. Defective material in a steam boiler is an offence for which there is really no excuse. Steel makers can now give us material equal to any possible requirements, and tests are easy which ensure excellence in every plate. Bad construction was formerly a fruitful cause of disaster, but in modern days there is no appliance of higher-class construction than a good Lancashire steam boiler. The dispensing with the punching of holes for drilling, and of hand-riveting for mechanical power, and the extensive use of machinery in shaping the plates, and the provision of strength for weak places, and the free allowance of expansion and contraction, make defective construction very exceptional. Boilers have exploded from over-pressure, but, as now made, no workable pressure reaches the boiler strength, and good boiler fittings prevent over-pressure being reached. No steam boiler ought to be allowed to work at a pressure exceeding one-half of its tested pressure—namely, one-fourth of its bursting pressure. Over-pressure is impossible with effective safety valves, and it is an offence against the law to have ineffective safety valves. Explosions have been made possible by overworking a boiler; the firing is excessive, and the plates cannot pass the heat; the plates become red hot, and the water rises from them. Of course the prevention of such accidents is simple, and no boiler should be overworked. When plates become red hot they lose their strength, and are not equal to the working pressure. If the water level is allowed to fall below the furnace crown, the plates in the upper part of the internal flues become so hot that they collapse. The boiler fittings already described easily prevent such an incident occurring; but, without relying too much upon these, a careful boiler attendant will see that the water level is kept fairly constant. Deposit upon the boiler plates within the boiler is to be guarded against. This deposit may be very hard and adhere firmly to the plates, or it may be soft and simply lie upon the plates. Whether hard or soft, this deposit, if not preventable, should be removed frequently, because, if not, the heat cannot pass, and expends itself upon the plates, simply burning them away. Boiler compositions are quack medicines, which have the usual pernicious influence upon the system, and the proper place for the treatment of bad water is not after

it enters the boiler, but before. The old arrangement of cold feed water was rich in its possibility of injury to the boiler, and the modern arrangement of hot and properly-distributed spray overcomes this defect entirely. Corrosive influences are to be avoided in steam boilers like the plague. Internal corrosion is avoidable by the treatment if necessary before entering the boiler of water chemically bad; external corrosion ought not to be possible, being caused by water or wet ashes lying in contact with the boiler plates, both of which occur through simple, absolute negligence. In addition to all these there is a wear and tear upon steam boilers which must not be allowed to escape notice. A boiler may develop cracks, as shown upon fig. 30, and a grooving may be set up, as shown upon fig. 31 (*see page* 52), the causes of which are not always easy to trace. The remedy is to thoroughly examine steam boilers periodically. There ought to be a thorough inspection internally and a good cleaning every month. Much may happen in a year. The period is much too long. Accidents with boilers have been brought about by incompetent firemen. It must not be forgotten that the very best boiler equipment may go wrong, and that a good deal must depend on the care of the attendant. It cannot be said that a large amount of skill is necessary in this class of workman, but vigilance should be a prominent trait in his character.

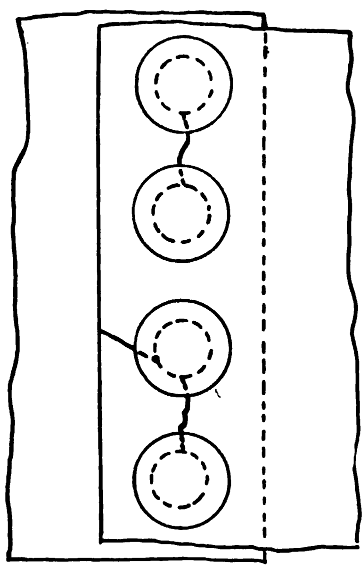


FIG. 30.

It must not be taken for granted that the writer is in support of those movements, of which Parliament hears something each now and again, of making it compulsory by law that the firemen at boilers should be compelled to hold certificates of competency, obtainable only by Government examination. It would be very easy to carry the examination

system much too far, and it must be remembered that there is nothing infallible in examinations, and there are occupations—even those of colliery managers—which no examination, written or verbal, in an examination room, can test the existence or otherwise of the really essential qualifications. How many candidates each year for colliery managers' certificates, possessed of the very qualities that are wanted in the administration and emergencies of a mine, are plucked because they cannot present a good written paper nor stand the catechising of examiners? And, on the other hand, how many candidates each year slip through because they write a beautiful essay or series of essays, and quite fascinate the

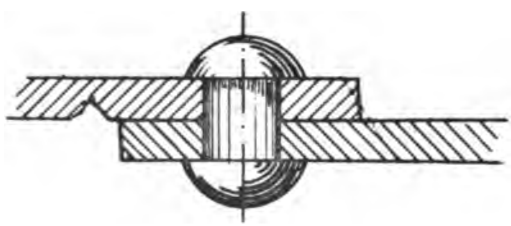


FIG. 81

examiners when being catechised? And yet they may be quite unfit for the administration of a mine. It is not suggested that such examinations should cease, because, with all their faults and failings, they have their advantages, and failing something better, which will come some day, we have to take these things as they are. But matters need not be made worse by the multiplication of examinations, and the granting of diplomas to the firemen at boilers. Such a system would introduce probably a superior class of workmen for this occupation, but not necessarily a better class. There is really not a great deal that a fireman at a boiler ought to know, and such knowledge that is necessary might be imparted to him, if he has anything in him, in a very short time. A fireman at a boiler should have some idea of how water is converted into steam, and he should understand the why and wherefore of the various fittings with which a steam boiler is equipped, and it is quite possible that very simple means would accomplish all that is necessary in this direction better even than putting in operation the machinery of a Government

Examination Board. The holding of such qualifications does certainly not diminish the natural conceit of an incompetent man, who thinks that after passing an examination his education and training are complete, and he sinks back into something worse than he was at first.

There are two matters in connection with steam boilers concerning which, whatever may already have been said, something further may still usefully be said. The appliances known as economisers have certainly borne out the truth of the name they bear, and have materially assisted in steam boiler economy. Their object is to take heat from the waste gases passing along the main flues from the boilers to the chimney, and imparting that heat to the feed water which is passing into the boilers. There is no necessity for argument to prove to any intelligent reader that hot feed water is the right thing; it not only saves so much fuel, but the feed water by being hot avoids any opposition action between the water and the steam, and improves the efficiency of the boiler as a steam generator. The waste of heat in boiler chimneys is enormous, and represents considerably more heat than what is converted into mechanical work when the steam is in action. The economisers take up this surplus heat, and instead of wasting itself in the chimney it is usefully applied in the feed water. The action of these economisers is as simple as it is effective: the feed water flows within the pipes towards the boilers, the hot gases act externally upon these pipes in passing to the chimney. It will readily be understood that the accumulation of soot upon the pipes would absolutely stop the passage of heat into the water; but to counteract this there is always a mechanical system under which scrapers slowly rising and falling prevent the accumulation of soot. It may be said that if we take the heat out of the gases and turn them into the chimney cold the chimney will lose its effect and there will be no draught. But all the heat, or anything like all the heat, is not taken out of these gases, and it will be readily understood that in no case will the gases become colder than the feed water; indeed, the gases will always be hotter than the hottest feed water, because to have any effect in the transmission of heat through pipes the heat external must be in excess of the heat internal. The heat left in the gases is ample for producing a good draught in the chimney.

The other point is with regard to smoke, and it can hardly be said that this smoke question rouses as much indignation as formerly. The local authorities have power to inflict penalties for the emission of black smoke over a period, and there are few chimneys who are not sinners at one time or another. Smoke may be produced either by insufficiency of air or insufficiency of the temperature in the boiler furnace. The hotter we can keep the fire the better, and everybody understands that a green fire produces smoke because it lowers the temperature, and under such conditions the air supply is hardly ever sufficient. In the opinion of the writer, mechanical stokers are the correct means of preventing smoke; they can be made to ensure the air supply, and the fire in the boiler furnace is always in a uniform condition—namely, green at the front and red at the back. No arrangement of mechanical stoking will enable us to force a steam boiler, and get so much work out of it as by hand-firing; and it need not be considered heresy to say that it is this impossibility to force which has retarded the deserved popularity of mechanical stoking. A good deal of smoke is caused because the installation of boilers is often insufficient. We try to work with two boilers when we ought to have three; and we try to work with four boilers when we ought to have six. No hand-firing can prevent smoke emission under such conditions. Hand-firing is a good deal in vogue, and it seems desirable that whilst a thick fire answers best with the air finding its way up between the bars, the firing should be frequent; and in a Lancashire boiler in which, after the Galloway fashion, the two furnace flues join into one, the firing of the two furnaces should be alternate. All good Lancashire steam boilers are fitted with grids in the firedoors, by means of which the supply of air above the fire can be regulated. They are a little wasteful, because it is easy to admit too much air; but a green fire giving off volatile matter requires substantially more air than a red fire, and the admission of air will check the emission of smoke.

BOILER FLUES AND SEATING.

Care and skill should be bestowed upon the seating of the boiler and the arrangement of the flues. The latter are arranged so that the hot gases emerging from the back end of the furnace tubes turn down and enter the bottom flue and

flow towards the front of the boiler. Near the front the volume divides, and returns to the main flue by way of the two side flues.

These flues, at the bottom and the sides, must be made of ample size, both for convenience in inspection and cleaning, and because small flues cause the hot gases to pass through at a high velocity, so that there is not sufficient time for a proper transfer of the heat to the boiler.

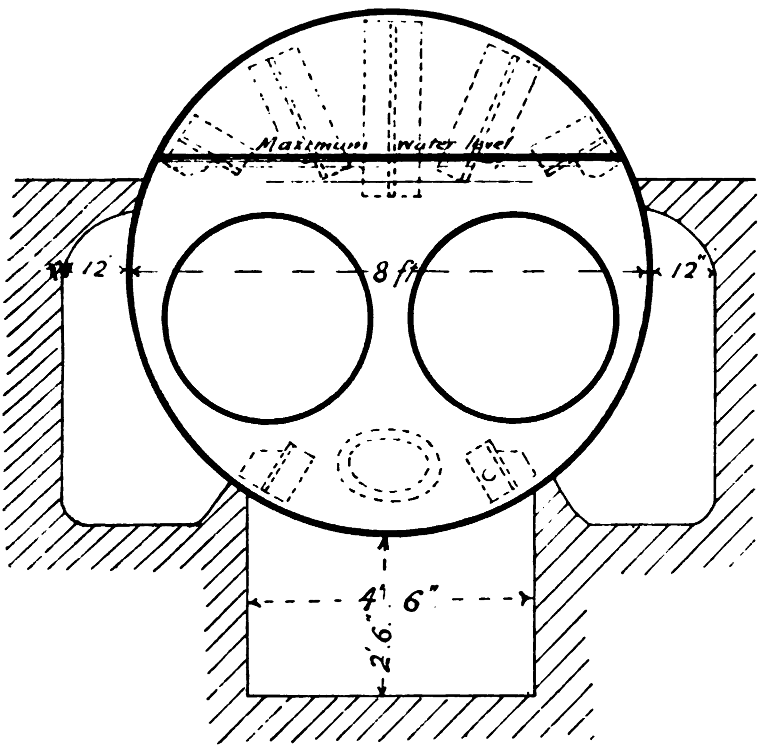


Fig. 32.
Showing the Dimensions of Flues and Seating.

The diagram, fig. 32, will be useful in giving an idea of the size of the flues. The top of the side flues should be about level with the crown of the furnace tubes, and they should be 12 inches wide at the top, the narrowest part. They are frequently made only 9 inches; but this is too small to enable a man to inspect the plates right up to the brickwork.

The bottom of the side flues is about level with the bottom of the boiler; the dimensions of the side flues are therefore fixed by the boiler. The bottom flue depends upon the size of the boiler, and the following figures will be useful:—

Diameter of Boiler.	Width of Bottom Flue.	Depth of Bottom Flue.
7 feet 6 inches	4 feet 3 inches	2 feet 6 inches
8 „ 0 „	4 „ 6 „	2 „ 6 „
8 „ 6 „	4 „ 9 „	2 „ 9 „

The boiler is usually set with a slight inclination, about $1\frac{1}{2}$ inch, towards the front, to assist in completely draining the boiler when it is emptied for cleaning. Experts, however, do not agree on this point, and the boiler is often set perfectly horizontally.

A Lancashire boiler, 30 feet by 8 feet, for a working pressure of 150 pounds, weighs from 24 to 25 tons, and contains about 17 tons of water. Such a boiler would cost, complete with all necessary fittings, £600 to £700.

HORSE POWER OF BOILERS.

Strictly speaking, although the expression is often used, it is not correct to refer to the horse power of a boiler. It is quite evident that the power developed by a boiler depends upon the engine or engines to which the boiler supplies steam.

Still, a practical rule may be useful, and the following is given for what it is worth:—With good non-condensing engines, using 4 pounds of coal and 30 pounds of steam per horse power per hour, multiply the grate area in square feet by 5. Thus a boiler 8 feet by 30 feet will have a total grate area of about 40 square feet, and 40 by 5 gives 200 horse power.

With good compound condensing engines, using 2 pounds of coal and 15 pounds of steam, multiply by 10 instead of 5; 40 by 10 equals 400 horse power. With a properly-proportioned economiser the power would be about one-eighth greater in each case.

GENERAL NOTES ON LANCASHIRE BOILERS.

The following general particulars relating to good modern practice in Lancashire boilers may be useful:—

Size: From 7 feet 6 inches to 8 feet 6 inches diameter, and

from 30 feet to 33 feet long. The most popular size would appear to be 8 feet by 30 feet.

Working pressure: From 100 to 200 pounds per square inch, 150 pounds being a fair average.

Construction: Shell, seven or eight rings of one plate each, bent cold to a true circle; the edges are butted together, and a cover strap inside and outside with four rows of rivets.

The circular seams are either single or double riveted.

The material used for the shell plate is mild Siemens-Martin steel, with a tensile strength of not less than 26 tons and not more than 30 tons per square inch.

Furnace tube plates, 24 tons to 28 tons.

The furnace tubes are usually 9 inches less in diameter than the radius of the shell. Thus a boiler 8 feet in diameter, 4 feet radius, or 48 inches, and 48 inches minus 9 equals 39 inches, or 3 feet 3 inches diameter of furnace tubes. The furnace tubes are built up of ten to twelve rings. The first and last rings are made slightly thicker than the others, and the diameter of the tube is coned down in the last ring but one to a diameter about 6 inches less than the normal.

Adamson's joints (fig. 14, *see page* 33) are commonly used for the furnace tubes.

The following figures will be useful as giving the thickness of the furnace tube plates for a boiler 8 feet diameter, furnace 3 feet 3 inches diameter :—

Working Pressure.	Distance between Flanged Joints.	Thickness.
100 pounds	3 feet	$\frac{7}{16}$ inch.
120 ,,	2 feet 8 inches	$\frac{15}{32}$,,
140 ,,	2 ,, 5 ,,	$\frac{17}{32}$,,
160 ,,	2 ,, 3 ,,	$\frac{9}{16}$,,
180 ,,	2 ,, 1 inch	$\frac{19}{32}$,,
200 ,,	2 ,,	$\frac{5}{8}$,,

The shell plates for such a boiler for 100 pounds pressure would be $\frac{9}{16}$ inch thick, for 150 pounds $\frac{3}{4}$ to $\frac{13}{16}$ inch thick.

NOTES ON THE WORKING OF LANCASHIRE BOILERS.

It may perhaps be useful to furnish, as briefly as possible, a few practical hints on the working and management of Lancashire boilers.

Starting Up.—In the starting up as well as in shutting off a boiler it is important that we "make haste slowly." Sudden changes of temperature and pressure are not calculated to do a boiler much good; on the contrary serious damage may result. Five or six hours is not too long a period to start up a boiler which has been off. See that the water is up to the proper level, and that all the fittings are in position and working order. Care must be taken to allow the air to escape from the boiler as the pressure gets up.

Blowing off for Cleaning and Inspection.—In letting off one of a range of boilers for cleaning, certain precautions are to be taken, both with a view to preventing injury to the boiler itself and for the protection of the men who have to enter the boiler when empty.

The damper should be closed, the stop-valve shut off, and the fires drawn; after which the boiler should be allowed to cool gradually, two or even three days being occupied in this process. The boiler may then be emptied of water. The object of the gradual cooling is the avoiding of sudden changes of temperature, which set up what may prove to be serious strains in certain parts of the boiler. The practice of blowing off a boiler under pressure cannot be too strongly condemned.

In the gradual cooling process it must be remembered that the internal pressure will not merely fall to that of the atmosphere, but, owing to the condensation of the steam, actually below the atmospheric pressure, producing a partial vacuum. This is to be avoided either by opening the top tap of the water-level gauge, when the pressure has fallen to a few pounds, or by raising the safety valve, or, better still, by opening a tester tap provided for the purpose. Similarly, all air should be allowed to escape from the boiler when starting up again.

Before entering the boiler care should be taken to see that the temperature has fallen sufficiently low, and that the boiler has been thoroughly ventilated. No attempt should be made to take off the manhole cover until the pressure has died down to that of the atmosphere.

The steam stop valve and the blow-off valve should be shut, and care should be taken to see that they are both tight. Fatal accidents through scalding, by steam or hot water entering a boiler in which men have been at work, have been far too

numerous, and are still reported from time to time. Simple precautions and the use of suitable appliances will entirely prevent such occurrences, which, after all, are largely due to negligence. The provision of isolating valves—both on the steam branch, between the stop valve and the main steam pipe (fig. 29, *see sheet* 3, *between pages* 44 *and* 45), and on the blow-off pipe, between the blow-off tap and the waste pipe—would effectually prevent either steam passing the stop valve into the boiler, or scalding water entering by way of the blow-off tap carelessly left open. When a boiler has been emptied it has sometimes happened that the blow-off valve has been left open, and has remained open after the workmen have entered the boiler. Subsequently, the blow-off tap of another boiler in the range has been opened to blow-off the sediment, and the scalding water has flooded into the empty boiler with, it may be, fatal results. The provision of an isolating valve (fig. 29, *see sheet* 3 *between pages* 44 *and* 45) renders an occurrence of the kind impossible.

Stoking.—In hand-firing two methods are possible, the right and the wrong. Unfortunately the latter is only too often the system adopted. It consists in shovelling large quantities of coal on the fires at long and irregular intervals. This means waste and black smoke. The fuel should either be spread evenly over the fire in small quantities at frequent intervals, or, better still, the coking system may be adopted. In this system the fresh fuel is deposited on the dead-plate in front of the fire bars, and gradually pushed back over the bars as fresh fuel is added from time to time. This system is closely imitated, is in fact perfectly carried out, by the mechanical stoker of Vicars. A fairly thick fire, with a proper draught, gives better results than a thin fire and a poor draught. From six to nine inches is a fair thickness of fire.

The mechanical stoker illustrated in figs. 33 and 34 (*see pages* 60 *and* 61) is manufactured by Messrs. T. & T. Vicars, of Earlestown, Lancashire. In action it carries out what has already been mentioned as the coking system of firing, and its especial advantages are economy in fuel consumption and the prevention of black smoke.

The appliance is entirely supported from the ground level, no drilling or attachment to the boiler front being necessary. Arrangements, however, are made so that the stoker can move

freely on its supports as the boiler expands and contracts. The fuel is fed from the hoppers or magazines into boxes, usually two to each flue, from which it is gradually pushed by reciprocating plungers or rams alternately on to the dead-plate. The furnace is designed at this point to facilitate the rapid

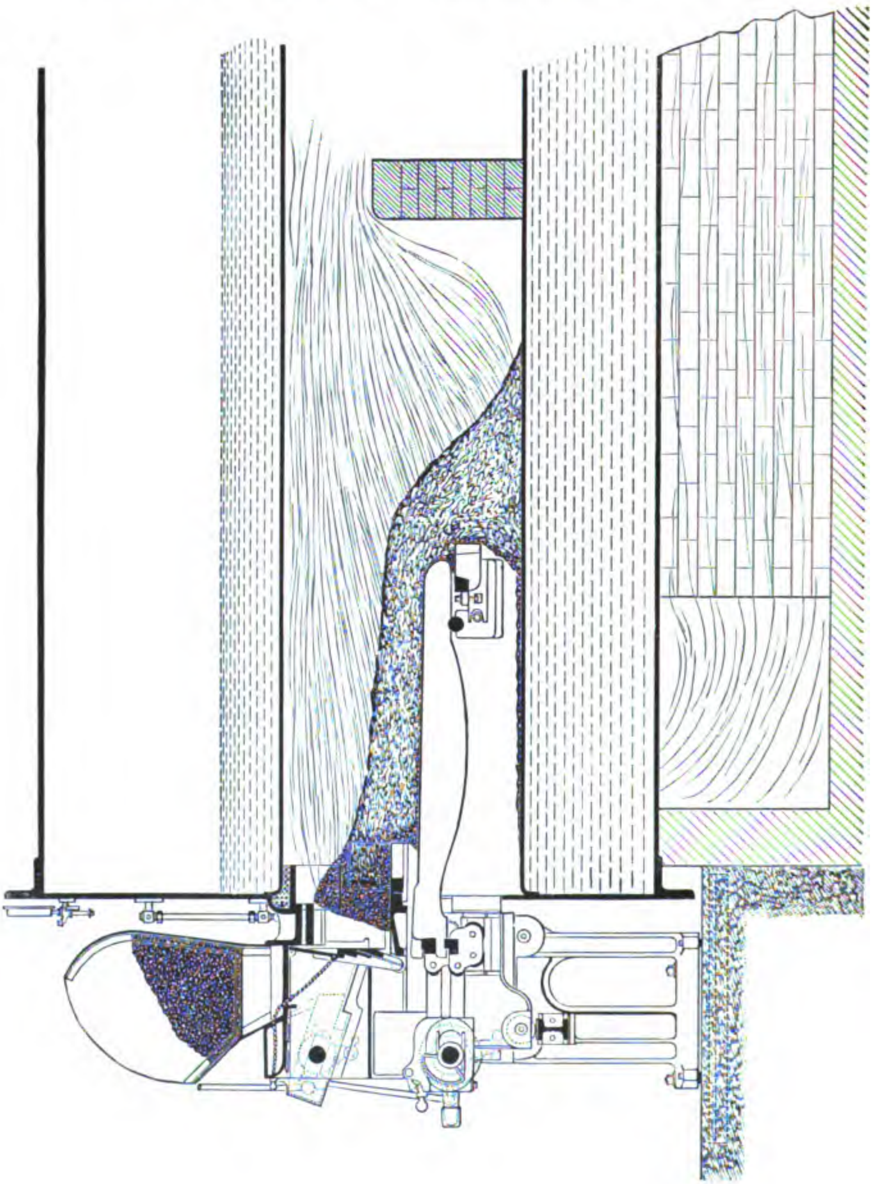


FIG. 88.—SECTIONAL ELEVATION OF VICARS' MECHANICAL STOKER.

coking of the fuel. From the dead-plate it is pushed on to the moving firebars, which gradually take the burning mass further into the flue. The partially-consumed coke, with the clinker and ash, is discharged over the end of the firebars into the flue, where they form and maintain a bank, which acts as a bridge, and prevents any free air passing direct into the flue. Combustion is completed at this point, and the clinkers are

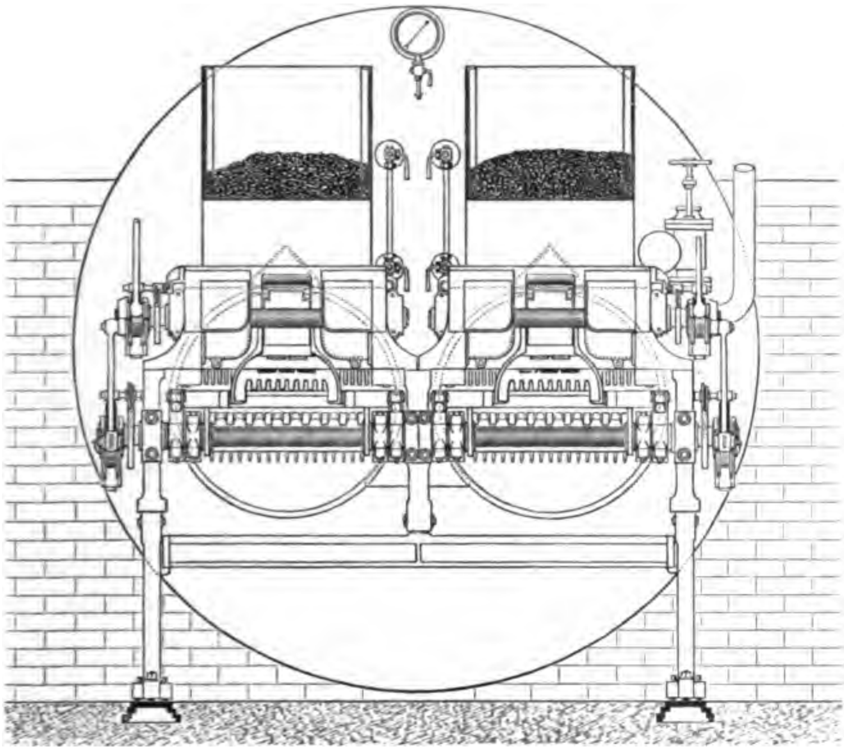


FIG. 34.
FRONT VIEW OF BOILER WITH VICARS' MECHANICAL STOKER.

removed at intervals according to conditions. A bridge of firebrick is built in the furnace flue some feet from the end of the bars, so as to form a sort of combustion chamber. The supply of fuel and the travel of the bars are regulated with facility and independently of each other, and the gear for working each flue is entirely separate. The coal feed is varied by altering the rate of motion of the plungers, which, by a simple

movement of a short lever, can be instantly adjusted to a wide range, or stopped altogether. This also applies to motion for bars, but the actual stroke of these can also be varied up to, say, four inches. The bars of each furnace are arranged in two sets, each composed of the alternate bars, and move together, travelling in towards the bridge, but return at separate intervals. Thus the fuel is carried inwards by the simultaneous action of both sets of bars, and remains in place without being disturbed by the return of either set. Each successive inward movement of the bars serves to carry the fuel, together with the clinker and ash, nearer to the end of the grate, where the mass at length drops over the end of the bars, as already described.

Feed Water.—The best system of supplying the water to make up for steam consumed is the continuous system, in which the water is delivered regularly to the boilers at the same rate the steam is consumed. The plan of intermittent feeding, allowing the water to get to a low level and then filling up, is bad.

Blowing off Scum and Sediment.—At frequent and regular intervals during the working of the boiler the blow-off tap and scum tap should be opened for the purpose of removing sediment and scum.

Removal of Ashes.—The common practice of raking out the ashes and allowing them to heap up against the boiler front, where they are slaked, cannot be too strongly condemned. Nothing tends to corrode and destroy a boiler sooner. A good plan is to provide iron barrows, and have the ashes raked directly into them to be wheeled away.

Explosions in Flues.—When a boiler has been standing with banked fires there is a tendency for combustible gases to lodge in the flues. This may result in an explosion when the dampers are opened and the fires broken up. Swivel dampers on vertical pins obviate this evil to some extent. In any case the damper should first be slightly opened, the air grids in the firedoors opened to get air blowing through, then the fire may be broken up.

Low Water.—A question was once asked, in an examination for colliery managers' certificates: If the water is found to be very low in a boiler, out of sight in the gauge glasses, with the

pressure up and a brisk fire, state fully what steps should be taken with the object of avoiding an explosion. One candidate, with an eye to the main chance, said he would take the longest and quickest steps possible. One can sympathise with this candidate's frank admission. History sayeth not what view the examiners took.

Other candidates said they would draw the fires, possibly the worst thing that could be done. The disturbing of the fire would result in a temporary increase of temperature, which might prove fatal. The proper course to adopt, if from any reason the water does get dangerously low, is to close the dampers and then carefully smother out the fires with earth, ashes, or anything that may be available. If the conditions are as bad as seemed to be indicated in the question above quoted, perhaps the wisest plan would be to warn everyone within reach and beat a hasty retreat.

The remedy is of course obvious. With proper appliances and reasonable care, the contingency is one of an almost impossible character.

FITTINGS FOR A LANCASHIRE BOILER.

In addition to the necessary dampers, firedoors, etc., the boiler should be provided with the following fittings, viz.:— Two safety valves, one being of the dead-weight type, the other may with advantage be of the high-pressure low-water type (fig. 26, *see page* 40); one steam-pressure gauge; two water-level gauges, with indicator to show the working level of the water, viz., from 10 inches to 12 inches above the furnace crowns; one check-feed valve, with perforated feed pipe; one scum tap, with scum trough; one junction or steam stop valve, with anti-priming pipe and isolating valve between the stop valve and the main steam pipe; one manhole and cover; one mudhole and cover; one blow-off tap, with isolating valve and copper elbow pipe; one fusible plug in the crown of the second or third ring of each furnace.

THE GALLOWAY BOILER.

Reference has already been made, in several places, to the Galloway tube, so largely used in Lancashire boilers, but this section would be incomplete without some mention of that special modification of the Lancashire boiler which bears the name of Galloway, a name which is accepted all over the world

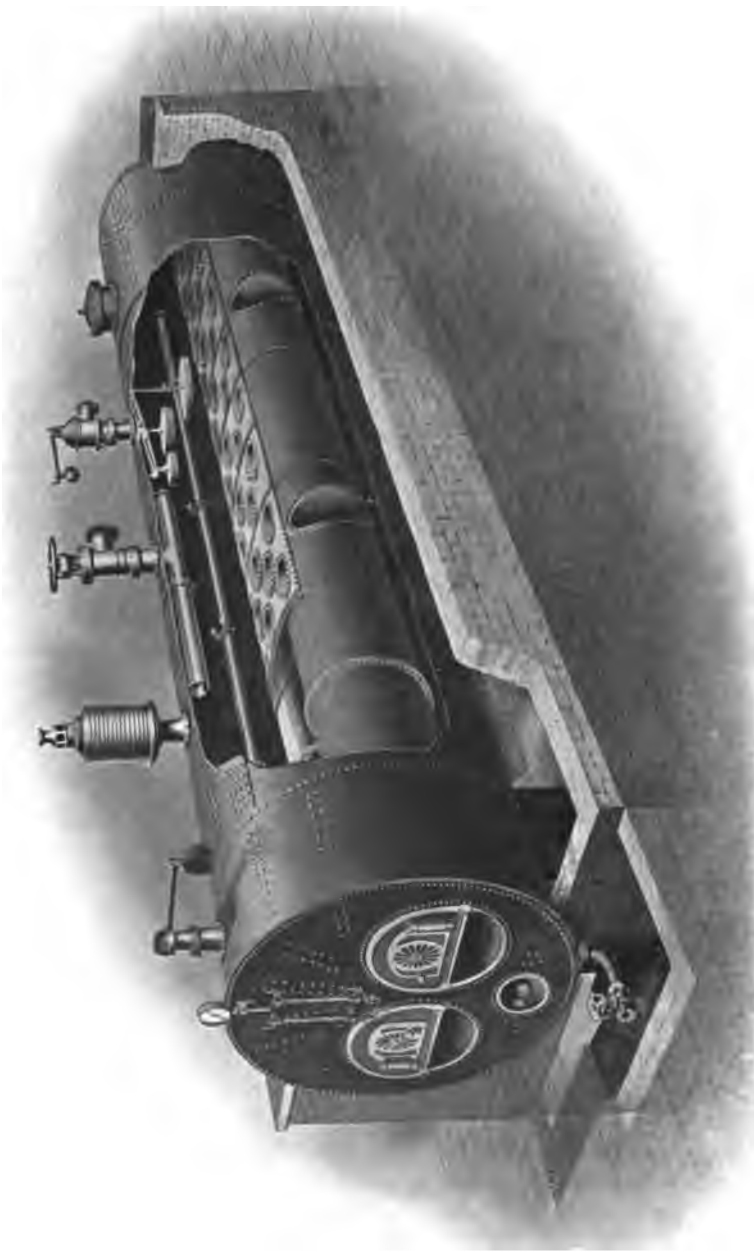


FIG. 85.—THE GALLOWAY BOILER.

as the hall-mark of excellence where boilers are concerned and all that appertains to boilers.

Messrs. Galloways Limited have been engaged in boiler manufacture for the last seventy years, and their boiler works at Ardwick, Manchester, is claimed to be the largest in the world, covering about seven acres, and finding employment for not far short of 1000 men. The works are equipped with machinery capable of performing every conceivable operation in boiler construction exactly as it ought to be performed, and the output of the works is practically one boiler per day.

Galloways Limited do not restrict themselves to the manufacture of the particular type of boiler to which they have given their name. They make the ordinary Lancashire and the Cornish boiler, together with others; but the Galloway boiler, illustrated in figs. 35, 36, 37, and 38 (*see pages* 64, 66, 68, *and* 69), is the one which they regard with pardonable pride as the best product of their seventy years of varied experience. Of this particular type of boiler alone more than 12,000 have been constructed, and the Galloway boiler is a deservedly popular steam generator in every part of the civilised world.

The general idea of the Galloway boiler is too well known to need much description, and the illustrations presented make the details of construction perfectly clear.

The intention is to provide as great an extent of heating surface as possible, to provide for perfect circulation, and to ensure increased efficiency and economy.

In outward appearance the Galloway boiler is to all intents and purposes a Lancashire boiler. Internally, however, there is a difference. At the front end the boiler is actually a two-flued Lancashire boiler, the furnace tubes being separate and of the usual shape and size. After the third ring, however, the furnace tubes unite, and are carried on to the end of the boiler, in the manner clearly shown in the illustrations. This large chamber, formed by the uniting of the two furnace tubes, is fitted with a number of the Galloway cone tubes, with the object of increasing the heating surface and improving the circulation.

The following particulars may be useful as showing the dimensions, etc., of these boilers. Of course other sizes are made. The figures given relate to the more popular sizes:—

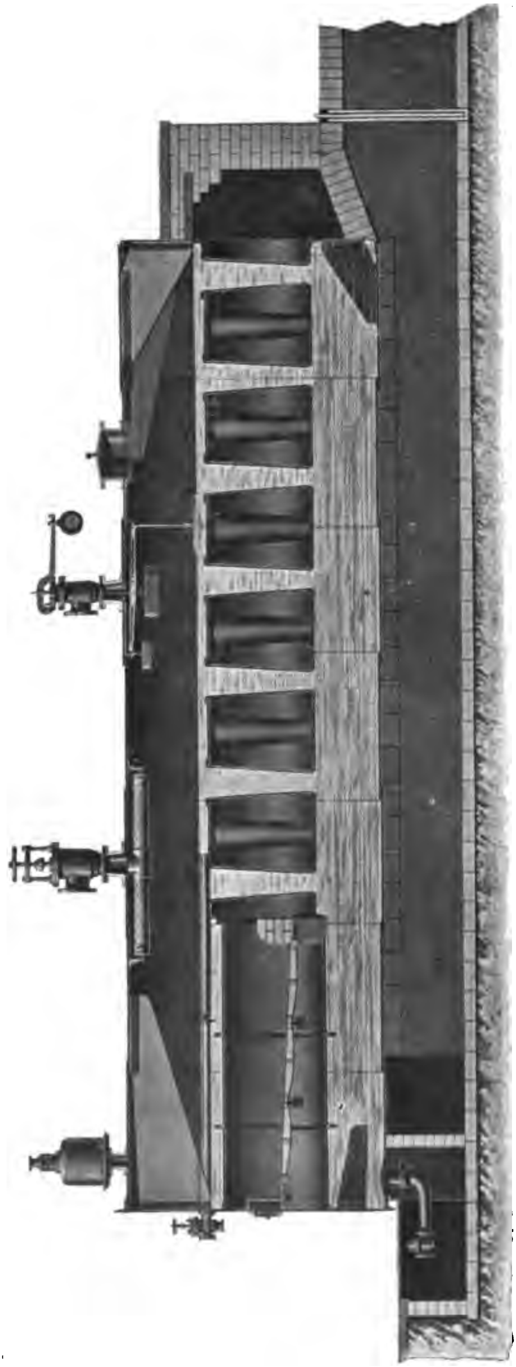


Fig. 36.

Longitudinal Section of Galloway Boiler Complete with Fittings.

Size.			Pounds of Water evaporated per hour.	I.H.P. at 20 pounds per hour.	Diameter of Furnaces.		No. of Cone Tubes.	Heating Surface in square feet.
ft.	ft.	ins.			ft.	ins.		
30 by	7	6	7200	360	3	0½	33	1052
30 by	8	0	8000	400	3	3	35	1120
30 by	8	6	9000	450	3	6	35	1211

The extent of heating surface, it will be noted, is considerably greater than in an ordinary Lancashire boiler of the same size. With good average fuel, and under reasonably good working conditions, the evaporation of the Galloway boiler is well over 12 pounds of water per pound of coal.

The following is an outline specification for a Galloway boiler, 8 feet diameter by 30 feet long, for 150 pounds working pressure:—

SPECIFICATION
FOR A
STEEL PATENT GALLOWAY BOILER.

THE SHELL.—The shell to be 30 feet long by 8 feet diameter, each ring to be in one plate three-quarters of an inch thick; the longitudinal seams to be butt-jointed, with inside and outside cover strips, secured by four rows of rivets, to break joint as much as possible, so as to avoid a continuous line of rivets. The edges of all the plates to be planed and fullered with a broad tool, and the holes drilled after the plates are placed in position by our own specially-designed machinery, the pitch being accurately regulated both longitudinally and transversely. All the riveting to be done by powerful hydraulic machinery. The first ring of the shell to be provided with a solid-welded angle ring for attachment to the end.

THE FLUE.—The interior to consist of two furnaces joining into one Galloway flue. The furnaces to be 3 feet 3 inches in diameter, solid welded longitudinally and flanged transversely by machine. The holes in these flanges and the strengthening rings between them to be drilled by specially-constructed machinery, so as to ensure exactitude in putting together, the whole being securely riveted up by hydraulic machine. The furnaces to unite behind the fire bridges into one patent Galloway flue, giving ample room for cleaning and examination, with increased strength. This flue to be supported by thirty-five patent Galloway cone tubes, all interchangeable and with the flanges square to the centre line of tube, thus putting less strain upon the material during manufacture. Four patent pockets to be fixed in the flue to divert the flame amongst the cone tubes. Also two patent expansion pockets at the back end to prevent the undue escape of the heated gases, and to give the necessary space in the end plate for expansion and contraction. The first ring of each furnace to be flanged for attachment to the front end plate, the flue being provided with solid-welded angle ring for connection to back end plate.

END PLATES.—The boiler ends each to be solid rolled in one piece three-quarters of an inch thick, the front plate securely attached to furnaces and shell, and turned up to its outer edge, the openings for furnace ends to be

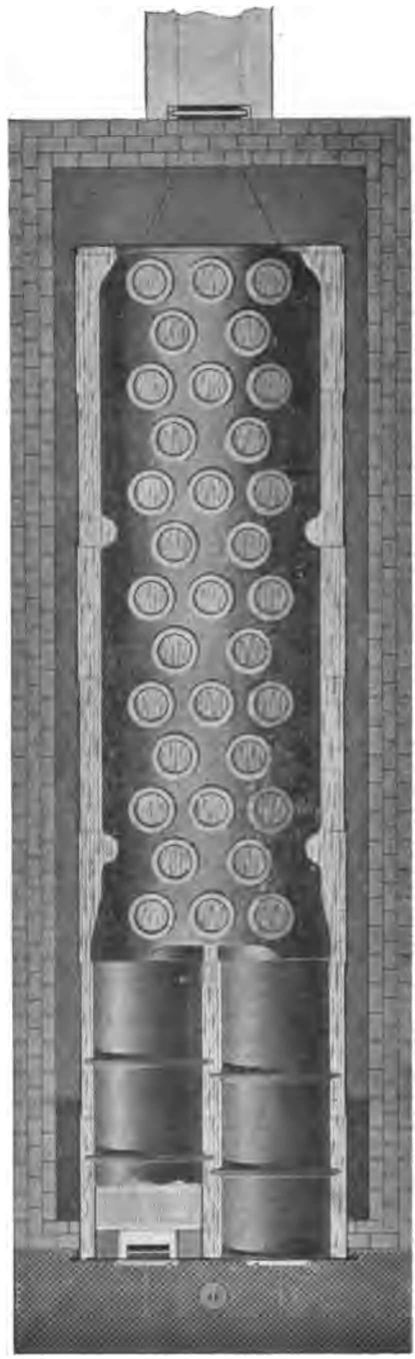


Fig. 37.
Sectional Plan of Galloway Boiler.

bored out by special machinery; the back end plate to be flanged on the outside edge and securely attached to flue and shell. These end plates to be efficiently stayed by suitable gusset plates secured by double angles to the boiler shell. The stays shall not be brought down too near the furnace crowns or Galloway flue, but sufficient space allowed for expansion.

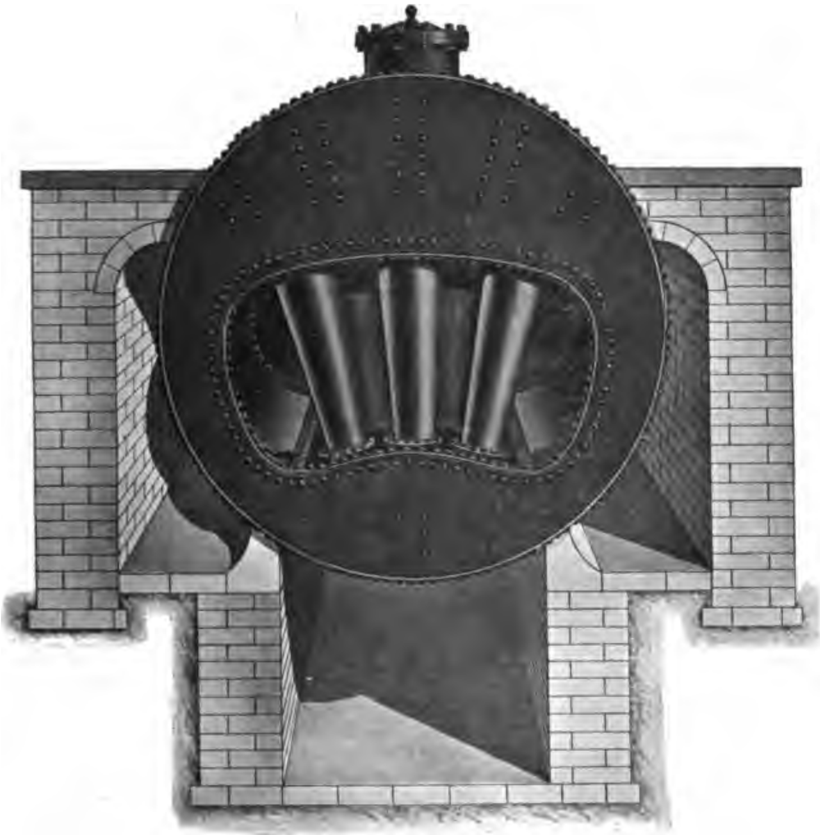


FIG. 38.

BACK END OF GALLOWAY BOILER SHOWING SEATING AND FLUES.

MANHOLES.—A strong wrought-steel mouthpiece of large size and massive section to be attached by double row of rivets to shell of boiler, the upper flange to be faced to receive wrought-steel cover secured by proper number of bolts and nuts. Also cast-iron one of smaller size on the front end plate below the furnaces, with faced flange and cover secured by bolts and nuts; guard plate also to be provided.

STAND PIPES.—Stand pipes to be riveted on the boiler where required, faced on their upper surfaces to connect the fittings to the boiler.

TESTING.—Before leaving our works the boiler shall be tested with a water pressure of 225 lbs. per square inch, a certificate of such test having been made to be furnished. The boiler to be afterwards well painted for transit.

MOUNTINGS FOR BOILERS.

FURNACE FITTINGS.—A set of wrought-iron fire frames to be fitted to the front end of the boiler, with brass beading round the furnaces. Doors of our registered design to be provided in the frames, each with internal baffle plate and brass circular slide to regulate the admission of air for the prevention of smoke; also cast-iron dead-plates, set of firebars of suitable design and length, bearing bars, tie rods, and cotters.

DAMPER.—Cast-iron damper and frame, with pulleys, chains, and weight to work from the front of the boiler.

FIRING FLOOR.—Floor frame and chequered plate, extending full width of boiler and side flues.

FLUE DOORS.—Two flue frames and doors for giving access to the side flues.

BLOW-OFF VALVE.—One gun-metal blow-off valve of our "parallel slide" type, fitted with locking gland to prevent removal of key, excepting when valve is shut. Also a suitable taper elbow pipe for attaching the valve to the stand pipe on the boiler.

FEED VALVE.—A 2½ inch Galloway "Perfect" feed valve; the valve loose from the spindle, so as to act as a check or non-return valve, and to be set down by means of a hand wheel and screw. Spindle to have external screw carried in gun-metal crossbar supported by wrought pillars; also connecting T piece outside, and perforated pipe inside the boiler for effectual distribution of the water.

SAFETY VALVE.—One 4 inch knife-edge lever safety valve, with graduated lever and weight. One Galloway high-steam and low-water safety valve (1901 patent). This design permits of the examination and re-grinding of the inner valve without emptying the boiler of water, breaking a pressure joint, or disconnecting the internal parts.

STEAM JUNCTION VALVE.—One six-inch Galloway "Perfect" steam junction valve (branch pattern) fitted up with gun-metal valve and seating, packed gland, hand wheel, etc., the spindle having external screw carried in wrought-iron crossbar, supported by wrought-iron pillars, fitted with Galloway's improved device for rotating valve on its seat whilst under pressure.

ANTI-PRIMING PIPE.—A cast-iron anti-priming pipe, perforated on the upper side, fixed inside the boiler and connected with the stand pipe for steam junction valve.

WATER GAUGE.—Two specially-made brass asbestos-packed sets of fittings for water gauges, with glass tubes and indiarubber washers; also brass water level pointer, connections, and pipe to carry away waste water. These gauges are to be self-closing in event of glass breaking.

STEAM GAUGE.—One steam pressure gauge of best construction with syphon.

[All these fittings are of the highest class, both of materials and workmanship, and are to special suitable designs.]

PLAN.—One complete plan to be provided, fully figured for bricklayers' use, showing the entire setting of the boiler, and the positions of the mountings.

FIXING GALLOWAY BOILERS IN POSITION.

The setting of the boiler in brickwork in its final position is a matter of importance, as it is necessary that the flues should be of proper proportions throughout, and that ample room should be given for the free passage of the gases as well as for inspection. In the case of the Galloway boiler, the flame, after leaving the furnaces and passing through the Galloway flue, where it is thoroughly broken up, and a great amount of heat absorbed by means of the Galloway tubes, divides at the back end and returns along the two side flues to the front, where it descends, re-unites,

and passes under the bottom of the boiler to the main flue, near which is placed the damper for regulating the draught. (*See fig.* 36, *page* 66.) In the Galloway boiler, where the circulation of the water is so perfect, owing to the large number of tubes, this arrangement is found to act excellently, but in plain Lancashire or Cornish boilers, where the same number of Galloway tubes cannot be introduced, and where, therefore, the circulation of the water is not nearly so perfect, it is advisable that the flame should return under the bottom first, so as to insure a more equable temperature of the water in the boiler, the gases afterwards rising and returning to the back by means of two side flues. This, however, necessitates two dampers to each boiler, which may be considered to a certain extent objectionable. We always recommend buff enamelled bricks for facing the front of the brickwork, so as to present a neat appearance, and induce the attendant to keep everything in perfect order.

In preparing the foundations a matter of great importance is that good drainage should be ensured, as it is found that serious damage in the way of corrosion often occurs to boilers owing to dampness which arises from the foundations, such outside corrosion not being caused by leakages from the boiler itself, but simply from being built either on wet ground or where surface water is allowed to accumulate. Care should also be exercised that the foundations are built on hard, well-burnt bricks, and the internal parts of the flue where exposed to the fire lined with firebrick; the boiler itself should also be carried upon blocks of the same material, specially made for this purpose, and it should be set having a fall of one inch towards the front end, so as to ensure the boiler being thoroughly drained of its contents when it is emptied for its periodical cleaning.

THE THOMPSON DISH-ENDED BOILER.

One of the most interesting developments in boiler construction which has come under the writer's notice, at least so far as Lancashire boilers are concerned, is the dish-ended boiler made by the firm of John Thompson, of the Ettingshall Boiler Works at Wolverhampton. Their experience of boiler-making extends over more than half a century, and the illustrations they have been good enough to furnish are deserving of careful consideration.

Attention has already been called to the fact that the weakest parts of the Lancashire boiler are the flat ends, and these have to be strengthened by means of the gusset stays, seven at each end, as previously illustrated. At the same time, the gusset stays give an element of stiffness which is scarcely compatible with the elasticity desirable to allow for the expansion and contraction of the boiler. The Thompson dish-ended boiler would appear to overcome these difficulties, and entirely dispense with the gusset and rod stays. The difference of construction will be evident from an inspection of figs. 39 and 40 (*see pages* 72 *and* 73), whilst fig. 41 (*see page* 75) shows this type of boiler in section, complete with the usual fittings, and in position on its seating. From this section it will be seen that we have to all intents and purposes

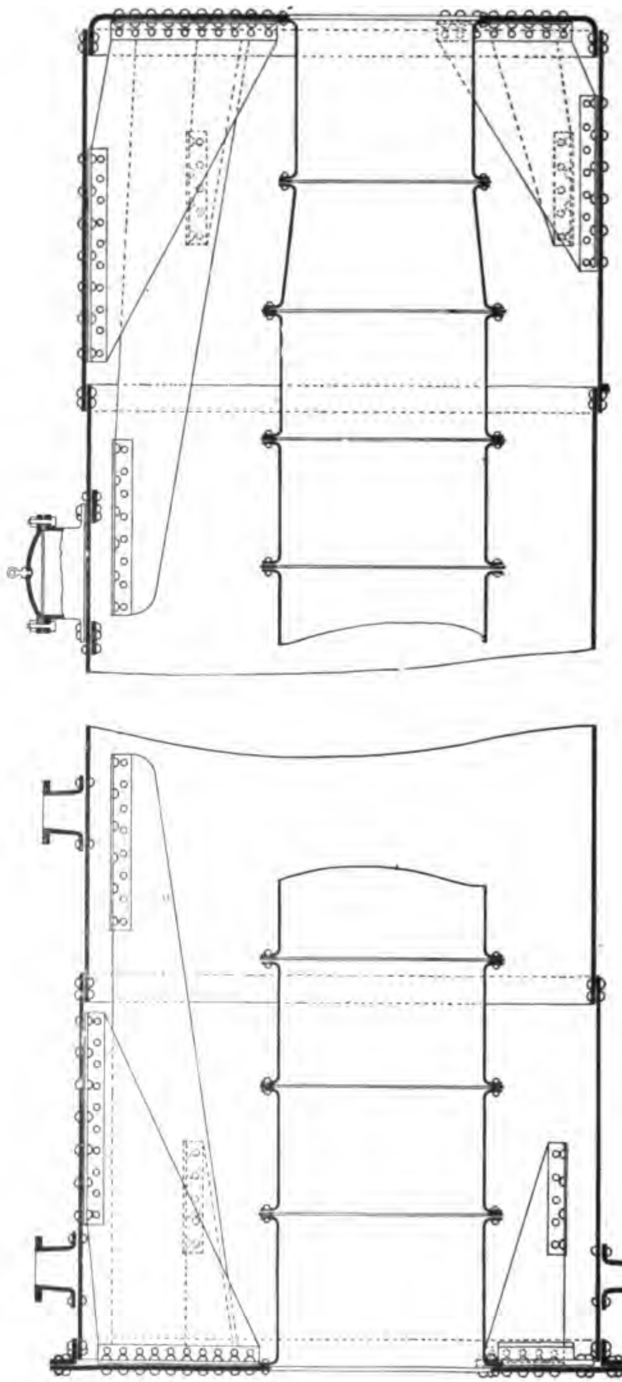


Fig. 39.
Showing the Ends of the Ordinary Lancashire Boiler

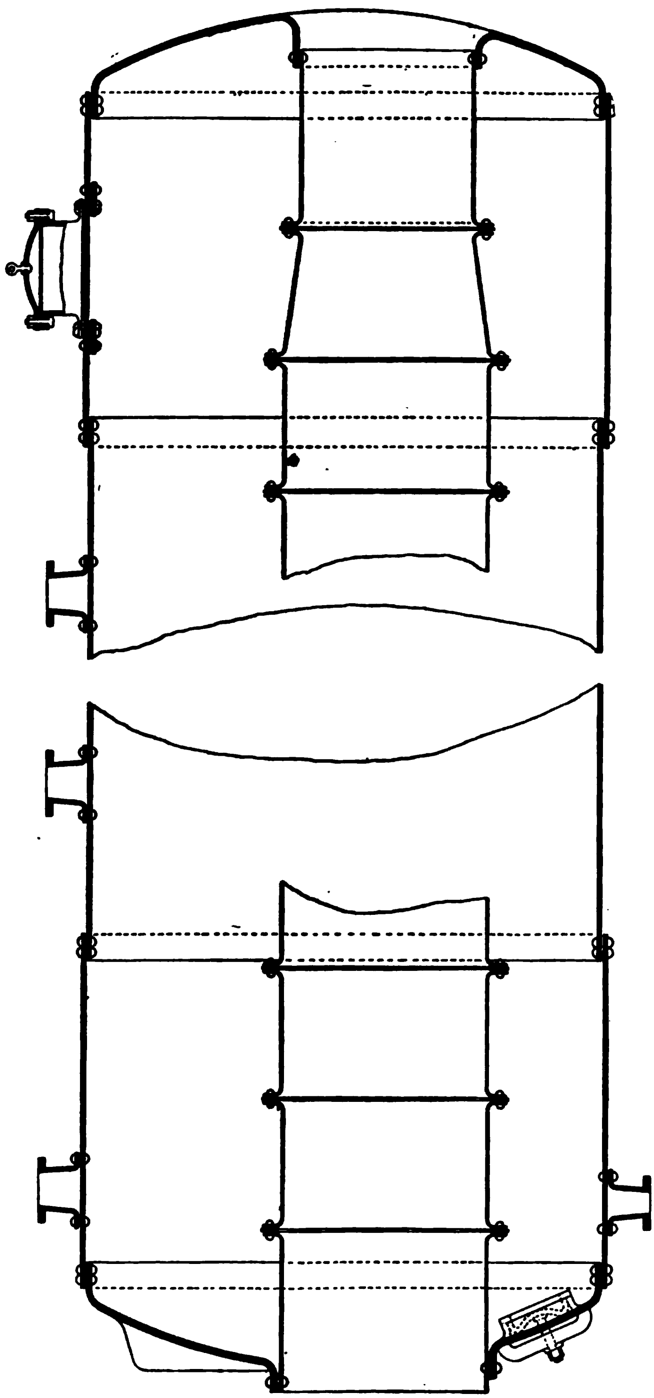


FIG. 40.
SHOWING THE ENDS OF THE THOMPSON DISH-ENDED BOILER.

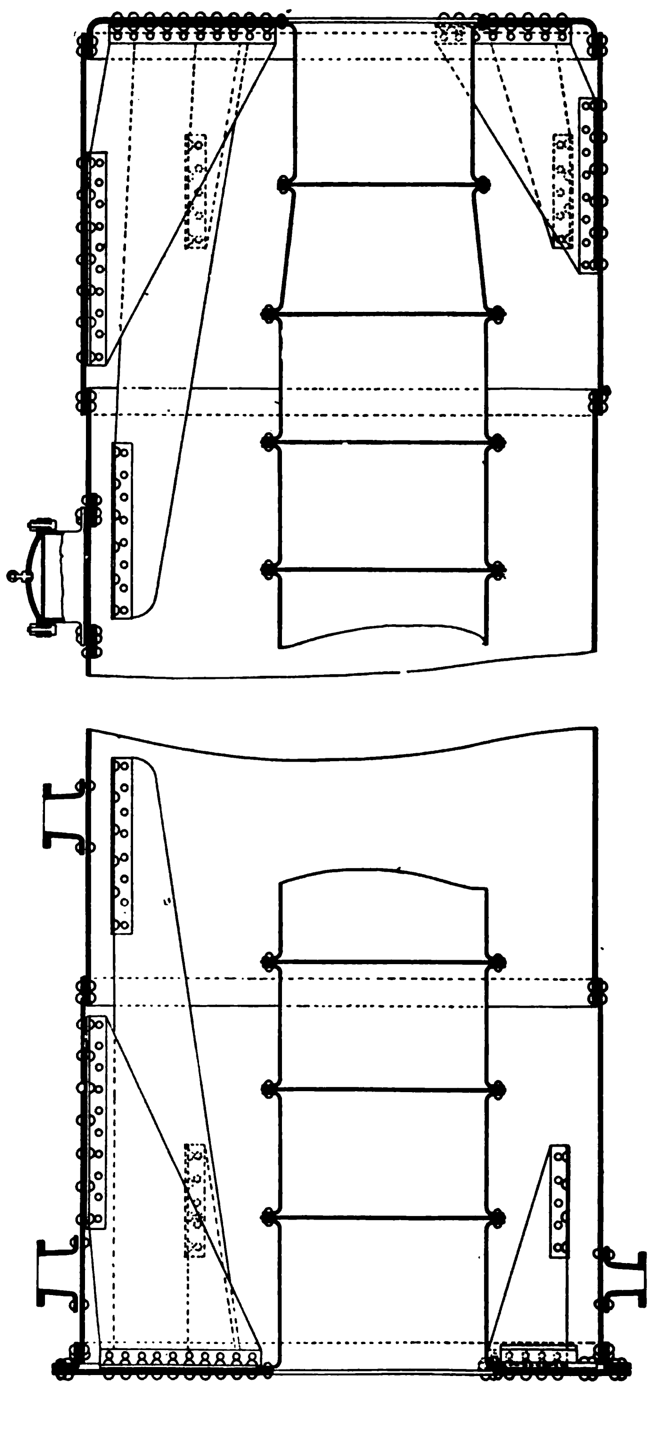


Fig. 39.
Showing the Ends of the Ordinary Lancashire Boiler

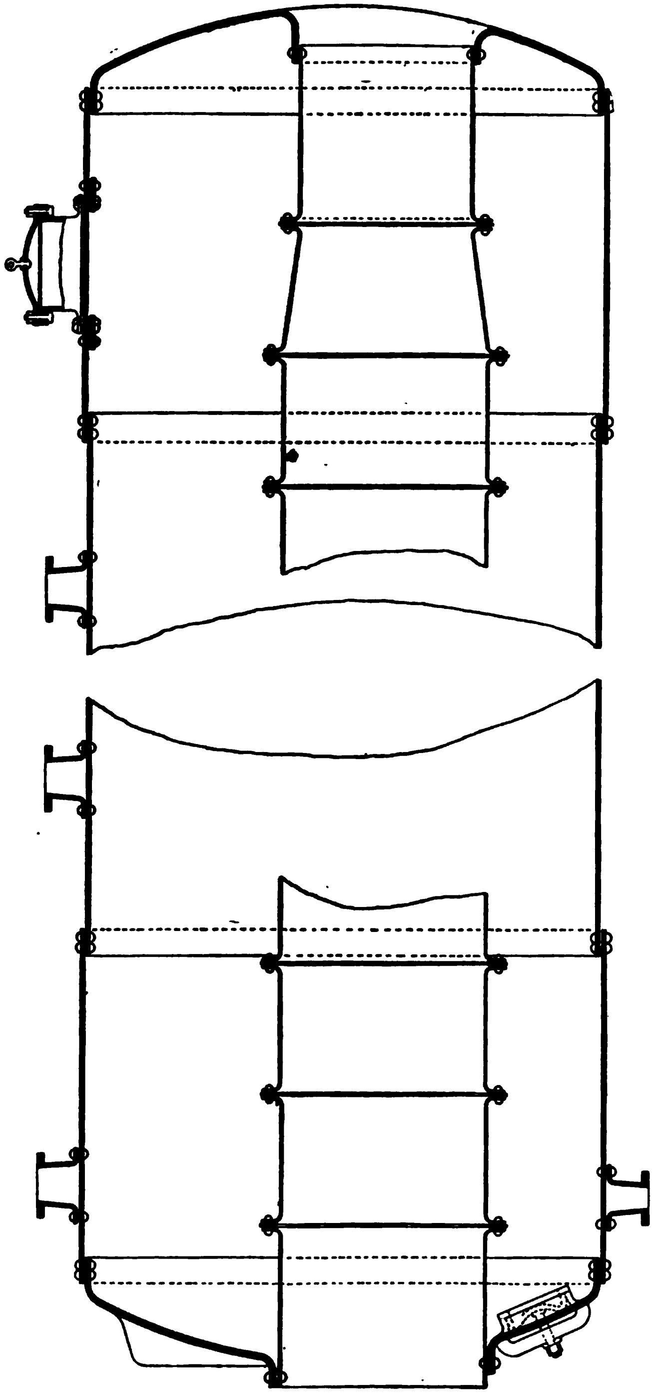


FIG. 40.
SHOWING THE ENDS OF THE THOMPSON DISH-ENDED BOILER.

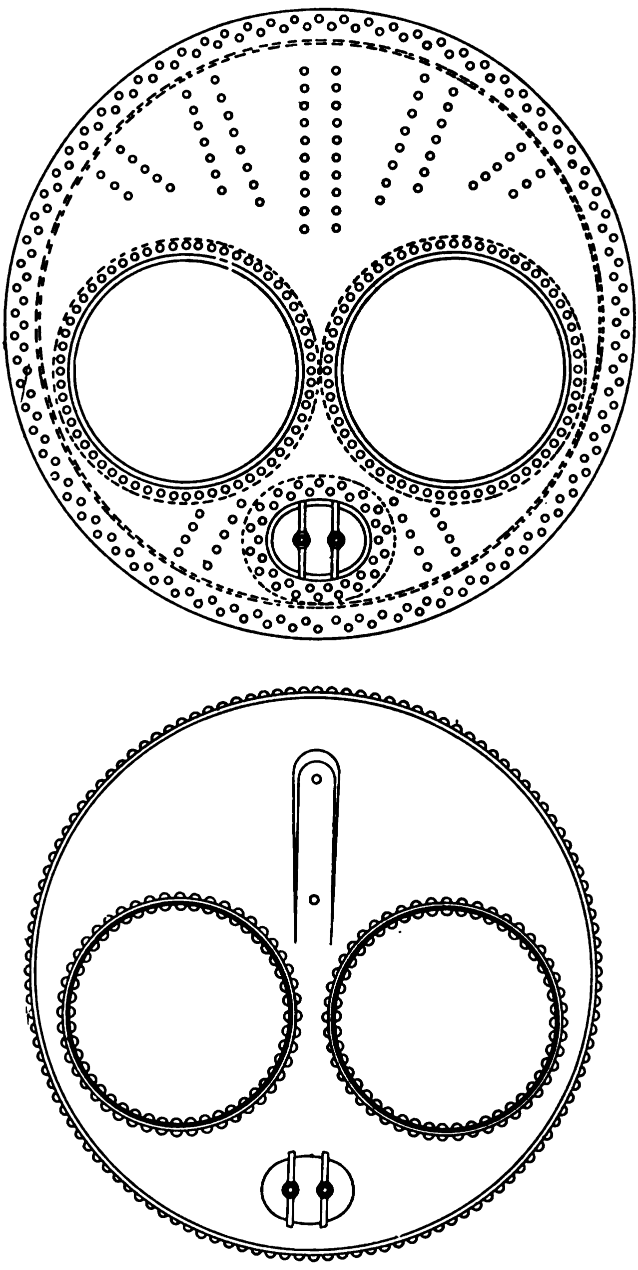


Fig. 40a.
Showing the Front Ends of Figs. 39 and 40.

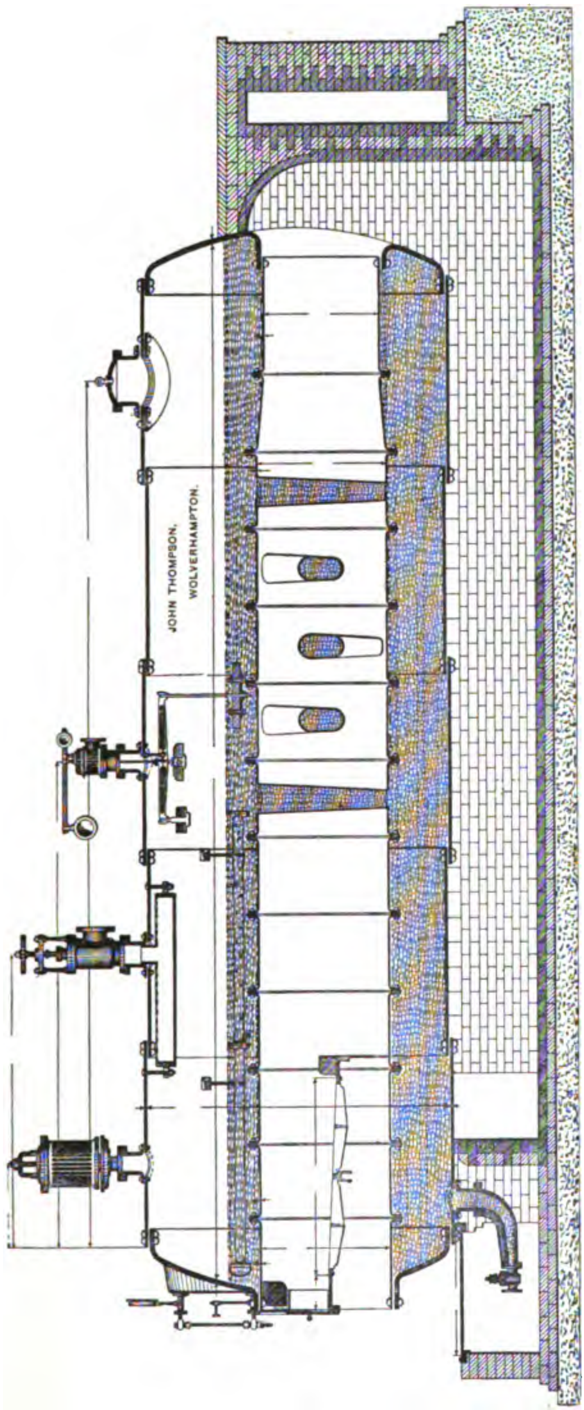


FIG. 41.
LONGITUDINAL SECTION OF THE THOMPSON DISH-ENDED BOILER, WITH FLUES AND FITTINGS.

a Lancashire boiler with the dish-shaped ends, but without either longitudinal bolt stays or gusset stays. The joints between the end plates and the shell plates, instead of being made with angle iron, as is usual with the front end of the ordinary Lancashire boiler, are made on exactly similar lines as the remaining circular joints, whilst the connection between the furnace tubes and the boiler ends is made in an exceedingly simple manner. Altogether the writer is very favourably impressed with the construction of this boiler, which has been installed in a considerable number of modern concerns, and has successfully stood the practical test of many years of working.

The end plates are made slightly thicker than usual, and are convex in shape, with flattened surfaces of small area provided for the attachment of the water gauges, feed valves, and scum tap, etc. The end plates are shaped by hydraulic pressure from plates of mild steel. It will be noticed that the amount of riveting is reduced to a minimum by this form of construction; and, what is even a still greater advantage, all the rivets are subjected to a shearing instead of a tensile strain. All the rivets are accessible for hydraulic riveting. The mouth of the furnace tubes being carried well out there is less liability for ashes to lodge against the boiler front. Internal cleaning is simplified by the absence of obstructions in the form of gusset stays.

The Thompson dish-ended boiler is made in the usual sizes, viz., from 6 feet 6 inches to 9 feet 6 inches diameter, and from 24 to 30 feet long for the usual working pressures. A boiler of this type for a working pressure of 150 pounds, 30 feet by 8 feet 6 inches—as represented in the section fig. 41 (*see page* 75)—has flues of 3 feet 5 inches diameter and 41 square feet of grate area. The heating surface amounts to 1100 square feet. Under fair average conditions of draught, fuel, and firing, consuming 20 pounds of fuel per square foot of grate area per hour, and assuming 8 pounds of water evaporated per pound of coal, this boiler is capable of evaporating 6560 pounds of water per hour. Supplying steam to engines consuming 20 pounds per H.P. hour this equals 328 I.H.P.; or, with compound condensing engines, requiring 15 pounds of steam, 437 I.H.P. The total weight, inclusive of all fittings, is 27½ tons.

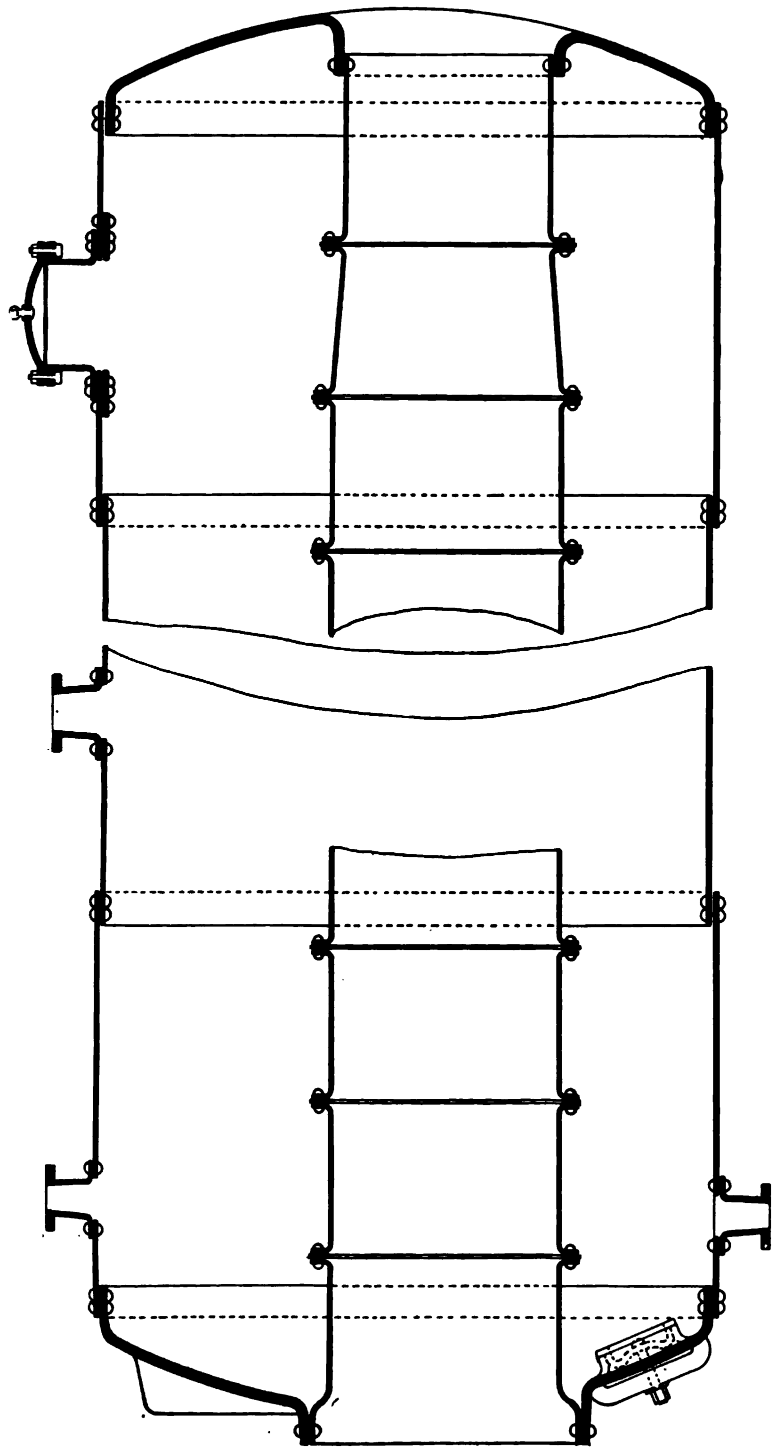


FIG. 42
SHOWING THE PATENT REMOVABLE FLUE.

REMOVABLE FLUES.

A further interesting development, made by the same firm, is a patent removable flue, illustrated in fig. 42. (*See page* 77.) In this arrangement the ends are specially flanged out to receive the flues. The front end section of the flue is also specially flanged back; this enables the flues to be withdrawn through the end plate, simply by cutting off the connecting rivets at either end so that new fireboxes or new flues may be inserted very quickly. Engineers who have had Lancashire boilers in their charge are aware that Lancashire boilers will work many years without requiring repairs, but when repairs have been necessary in the past they have proved very costly through the failing of the flue, which necessitated cutting off the front end plate and all the stays and replacing with new fireboxes or flues. This has taken considerable time; and, moreover, owing to the large amount of hand-riveting work, it was often a leaky and unsatisfactory job when finished. With this patent form of removable flue new flues or fireboxes can be put in at a little cost; and, moreover, there being so few rivets required to be put in by hand, and no stays, the work can be well done and a sound job made, even for high pressures. This combined form of Thompson dish-ended boiler with patent removable flues is coming very much to the front, and we understand a large number have been constructed of varying sizes up to 9 feet 6 inches diameter.

BOILER INSURANCE AND INSPECTION.

It may not be considered out of place in a work of this character to say a word in favour of boiler insurance.

Boilers should, of course, be minutely inspected at regular intervals by properly-appointed competent officials in the employ of the colliery; but it is of great advantage to insure the boilers with one of the several excellent insurance companies which devote themselves to this particular business. These companies, at least the larger ones, undertake the inspection not only of boilers but also of steam engines and electrical machinery.

They employ expert engineers, who investigate and report on the working and condition of the engines and boilers, and it is often useful to have the reliable opinion of an independent expert. They will also undertake the testing of steam engines and electrical machinery, and furnish reports upon the efficiency,

pointing out defects where they exist, and suggesting remedies and improvements. The amount paid in premiums for the insurance is well expended, if only for the satisfaction of having these tests, inspections, and reports by independent experts.

ECONOMY IN STEAM GENERATION.

Reference has already been made to the enormous difference between the theoretical energy capacity of coal and the actual development of energy in practice. To put the matter in a nutshell it amounts to this, that with good high-class engines and boilers, worked under favourable conditions, the energy developed in the steam cylinders is only about 9 per cent of the energy in the coal, *over 90 per cent being absolutely lost.* Nearly one-fourth of the energy in the coal passes away up the chimney in the form of waste heat and unconsumed gases, and more than one-half is lost in the exhaust from the engine. These figures, it must be remembered, relate to the working of good high-class engines and boilers; possibly the average condition of things at a colliery—indeed, there can be little doubt of it—is far worse.

Our attention is therefore directed to the possible means of effecting economy in steam raising, and we are led to speak of economisers, superheaters, mechanical draught, and independent condensing plant.

ECONOMISERS.

One somehow naturally associates with this word, in connection with steam plant, the name of Green. For more than half a century the firm of Messrs. E. Green & Son Limited, of Wakefield, has been identified with the manufacture and development of this valuable adjunct to the steam boiler. Messrs. Green have placed at the writer's disposal not only a considerable amount of useful information bearing upon steam generation generally, but have also furnished some excellent illustrations, which are referred to later.

In the economiser the idea is to intercept and utilise some of the waste heat which otherwise passes away up the chimney.

Take the case of a boiler working at, say, 150 lbs. per square inch; the temperature of the steam and water in the boiler will be about 360 degrees F., and it follows that the hot gases leaving the flues must at least be higher than this. As a

matter of fact the temperature of the flue gases would probably be 650 or 700 degrees F.

Green's economiser utilises this heat, or some portion of it, for heating the feed water, so that instead of pumping cold water into the boiler, on which the coal has to expend heat in raising it to 360 before it begins to give off steam (at 150 lbs. pressure), the water is delivered into the boiler already heated up to from 200 to as high as 340 degrees.

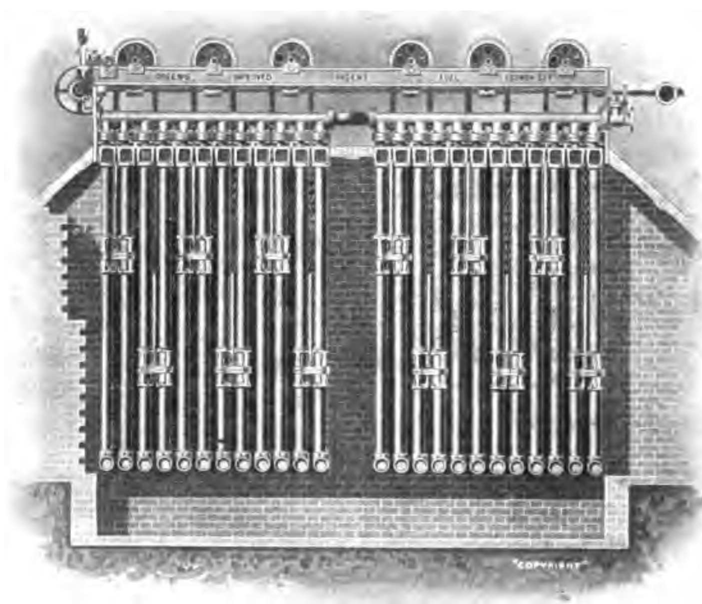
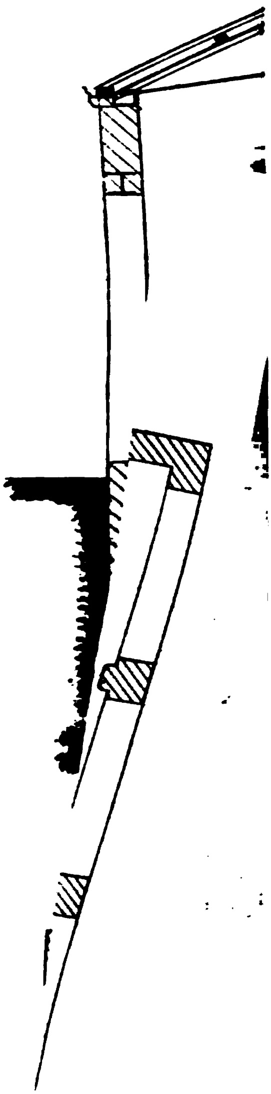


Fig. 43.
Green's Economiser.

The arrangement is clearly shown in figs. 43, 44, and 45. (*See sheet* 4, *between pages* 80 *and* 81.) It consists of a number of tubes fixed vertically in a chamber constructed in the main flue; the tubes are of cast iron of a special mixture, 9 ft. long and about $4\frac{1}{2}$ in. in diameter. These are arranged in stacks, and the feed water enters at the bottom of the arrangement, from the injector or feed pump. The water enters at the end of the economiser



nearest to the chimney, and emerges from the top of the arrangement at the other end, where the hot gases first enter.

Each tube is fitted with external scrapers, which continuously slowly rise and fall whilst the boilers are working, the object being to keep the external surfaces free from deposits of soot, which, being a bad conductor of heat, would interfere with the proper working of the appliance.

It is important that the feed water, as it enters the economiser, should already be heated to about 90 degrees, otherwise moisture condenses upon the tubes where the cold water comes in, causing corrosion, as well as tending to make the soot cake upon the tubes. This warming of the water is effected by taking a small pipe from the hot-water outlet from the economiser, and connecting with the suction of the feed pump; the cold water is thus warmed up to about 90 degrees before entering the economiser tubes. The economiser should be blown off for a few minutes each day, by means of valves provided for the purpose, and the whole arrangement, like the boilers, should be thoroughly examined and cleaned at regular intervals. A safety valve is provided, which is loaded to blow off at a slightly higher pressure than the boiler, not exceeding 20 lbs. per square inch above the boiler pressure, and a relief valve, to blow off at a lower pressure than the safety valve, is placed upon the delivery pipe from the pump.

A pressure gauge and also a thermometer ought to be provided in connection with the hot-water outlet from the economiser.

The economy effected in fuel amounts to from 15 to 25 per cent of the total fuel consumption. The fuel gases are reduced in temperature from an average of 650 on the boiler side of the arrangement to 350 on the chimney side, and the temperature of the feed water is increased on an average to 200 degrees F.

Messrs. E. Green & Son furnish the two following tables, which are useful and interesting as showing the percentage saving effected in fuel consumed by the use of a properly proportioned economiser for the heating of the feed water.

The first table is calculated for boilers working at 100 pounds, and it shows at a glance the percentage saving as compared with the fuel consumed before adopting economisers, and assuming the boilers did not previously require heavy firing. Thus, with feed water entering the economiser at 90 degrees F., and heated up to 240, there is a saving of over 13 per cent

(13·305). If the boilers had previously required heavy firing the saving would be still greater. Percentage of fuel saved :—

Final Temperature	INITIAL TEMPERATURE OF WATER.											
	40°	50°	60°	70°	80°	90°	100°	120°	140°	160°	180°	200°
100	5·1	4·285	3·456	2·616	1·758	·887	·00					
120	6·8	5·999	5·184	4·36	3·516	2·061	1·79	·00				
140	8·5	7·713	6·912	6·104	5·274	4·435	3·58	1·822	·00			
160	10·2	9·427	8·64	7·848	7·032	6·209	5·37	3·644	1·858	·00		
180	11·9	11·141	10·368	9·592	8·79	7·983	7·16	5·466	3·716	1·892	·00	
200	13·6	12·855	12·096	11·336	10·548	9·757	8·95	7·288	5·574	3·784	1·93	·00
220	15·3	14·569	13·824	13·08	12·306	11·531	10·74	9·11	7·432	5·676	3·86	1·968
240	17·	16·283	15·552	14·824	14·064	13·305	12·53	10·932	9·29	7·568	5·79	3·936
260	18·7	17·997	17·28	16·568	15·822	15·079	14·32	12·754	11·148	9·46	7·72	5·904
280	20·4	19·711	19·008	18·312	17·58	16·853	16·11	14·576	13·006	11·352	9·65	7·872
300	22·1	21·425	20·736	20·056	19·338	18·627	17·9	16·398	14·864	13·244	11·58	9·84

(Green's Economisers.)

The second table can be used for all working pressures up to 200 pounds. An example will make its application clear. Take the case already given, feed water entering the economiser at 90 and leaving at 240. Multiply the difference, that is 150, by the figure found under the working pressure—in this case 100 pounds—and opposite the initial pressure 90, which is found to be ·0887; thus, 150 × ·0887 = 13·305 per cent, the result already obtained from the former table. Now take the same temperature, but a working pressure of 160 pounds, 150 × ·0879 = 13·185 per cent saving.

Initial Temp. of Feed.	WORKING PRESSURE IN BOILERS. Pounds per Square Inch.											Initial Temp. of Feed.
	0	20	40	60	80	100	120	140	160	180	200	
32°	·0872	·0861	·0855	·0851	·0847	·0844	·0841	·0839	·0837	·0835	·0833	32°
40	·0878	·0867	·0861	·0856	·0853	·0850	·0847	·0845	·0843	·0841	·0839	40
50	·0886	·0875	·0868	·0864	·0860	·0857	·0854	·0852	·0850	·0848	·0846	50
60	·0894	·0883	·0876	·0872	·0867	·0864	·0862	·0859	·0856	·0855	·0853	60
70	·0902	·0890	·0884	·0879	·0875	·0872	·0869	·0867	·0864	·0862	·0860	70
80	·0910	·0898	·0891	·0887	·0883	·0879	·0877	·0874	·0872	·0870	·0868	80
90	·0919	·0907	·0900	·0895	·0888	·0887	·0884	·0883	·0879	·0877	·0875	90
100	·0927	·0915	·0908	·0903	·0899	·0895	·0892	·0890	·0887	·0885	·0883	100
110	·0936	·0923	·0916	·0911	·0907	·0903	·0900	·0898	·0895	·0893	·0891	110
120	·0945	·0932	·0925	·0919	·0915	·0911	·0908	·0906	·0903	·0901	·0899	120
130	·0954	·0941	·0934	·0928	·0924	·0920	·0917	·0914	·0912	·0909	·0907	130
140	·0963	·0950	·0943	·0937	·0932	·0929	·0925	·0923	·0920	·0918	·0916	140
150	·0973	·0959	·0951	·0946	·0941	·0937	·0934	·0931	·0929	·0926	·0924	150
160	·0982	·0968	·0961	·0955	·0950	·0946	·0943	·0940	·0937	·0935	·0933	160

The heating surface in Green's economiser works out to 10 square feet per tube. The arrangement should be so proportioned to get the best results that the apparatus empties itself once per hour.

FIG. 46.
GALLOWAY'S SUPERHEATER.

RULE TO CALCULATE THE SIZE OF AN ECONOMISER.

To ascertain the number of tubes required in a given case the following rule is useful:—Divide the quantity of water in

gallons, evaporated per hour by $6\frac{1}{4}$. Example: An economiser is wanted for three boilers, 30 feet by 8 feet, working at 120 pounds and evaporating 1600 gallons per hour—1600 divided by $6\frac{1}{4}$ equals 256 tubes.

SUPERHEATERS.

In steam engines which are worked expansively—and most modern engines are so worked—difficulty is frequently experienced as a result of the partial condensation of the steam in the cylinder. It must be understood that there is a distinct relationship between the pressure and the temperature of what is called saturated steam—that is, the steam as it comes from the surface of the water in the boiler. Any lowering of the temperature results in the partial condensation of the steam, and since a lowering of the pressure brings about a lower temperature, it will be seen that in the course of expanding in the steam cylinder, not only the pressure but the temperature is lowered, with a certain amount of condensation. The object of the superheater is to give the steam, after it leaves the boiler, a certain extra store of heat which is held in reserve, so to speak, permitting the steam to expand to a lower pressure whilst still having a temperature sufficiently high to prevent condensation.

The superheater consists of an arrangement of tubes placed usually at the back end of the boiler, in the hot gases emerging from the boiler flue. The steam from the boiler passes through the tubes, taking up an extra supply of heat before reaching the steam engines. The superheater illustrated in fig. 46 (*see page* 83) is that of Messrs. Galloways Limited, a name inseparable from steam boilers and all that appertains to steam boilers.

It is made entirely of Siemens-Martin mild steel, and is fully as strong as any part of the boiler. The sketch, fig. 47, shows the Galloway wrought-steel superheater in position at the back end of the boiler.

Superheating, however, must not be indulged in indiscriminately; engines which have not been constructed to work with superheated steam should not be supplied with steam which has anything but a very moderate degree of superheat. Steam may be heated up to 650 or 700 degrees F.; but at this temperature special care has to be taken both in the design of

the engine and the materials used. Special attention must also be given to lubrication; ordinary cylinder oils are useless at this high temperature.

A high degree of superheat, however, will rarely be adopted or required at collieries; superheating to about 100 degrees above the saturation temperature will give desirable economy without incurring any of the risks of excessive superheating.

But the cooling of the hot gases by the use of economisers and superheaters may be carried to such a point that the

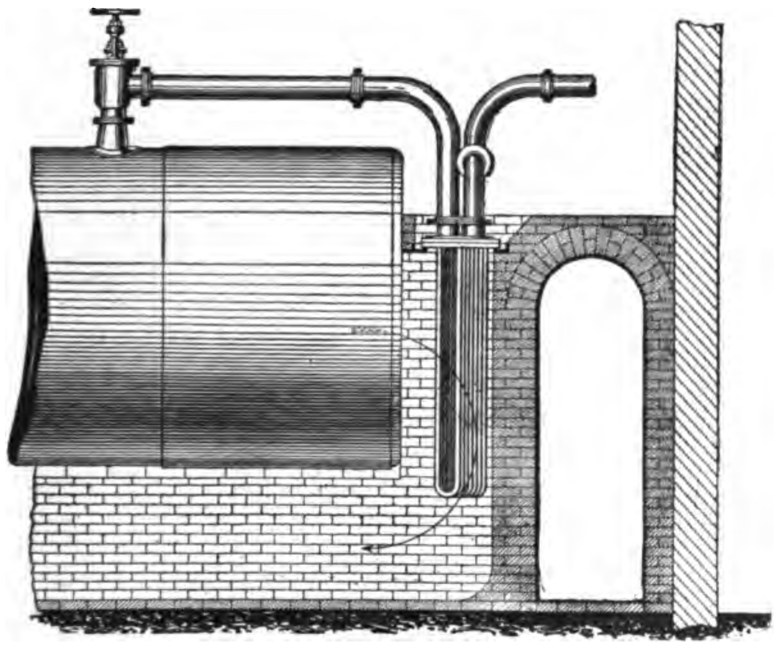


FIG. 47.
SHOWING GALLOWAY'S SUPERHEATER IN POSITION AT END OF BOILER.

temperature is too low to produce an efficient draught to effect the combustion of the fuel in the boiler furnace. Indeed, on the score of economy alone, the ideal arrangement would be a number of economisers with water in successive stages of heating, until practically all the heat developed by the coal had been absorbed, a result which is scarcely possible in practice. It is possible, however, so to lower the temperature of the hot gases from the boiler flues that it becomes necessary to provide some other and more economical means of maintaining a

sufficiently vigorous draught than is afforded by the heated column in the chimney.

Now just as furnace ventilation is far more costly than fan ventilation, so also is chimney draught as compared with mechanical draught. A tall chimney, capable of maintaining a vigorous draught for a large range of boilers, is a costly luxury both as regards initial outlay and fuel consumption.

The complete induced draught arrangement would appear to be one in which the hot flue gases are utilised both for

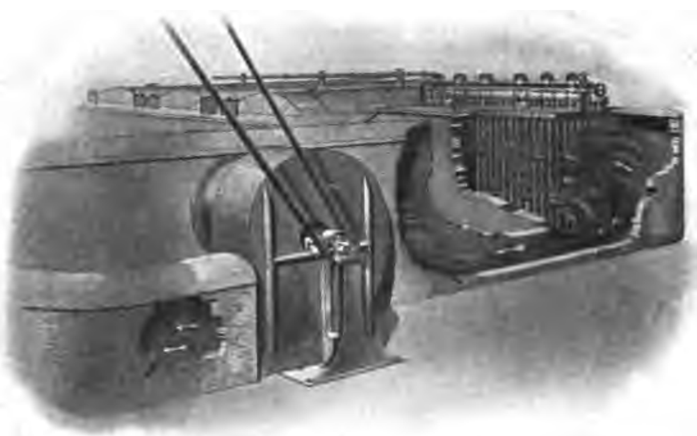


FIG. 48.
SHOWING ECONOMISER, WITH INDUCED DRAUGHT.

superheating the steam and for heating the feed water. In superheated steam the temperature is raised to a higher degree than that due to the working pressure of the boiler, and in engines supplied with superheated steam the advantages of working expansively or compounding are more fully realised.

A well-designed fan for an induced draught arrangement (fig. 48) is a comparatively inexpensive appliance, and the power for driving it amounts to less than 1 per cent of the power developed by the engines supplied by the boilers. It enables almost any kind of fuel to be consumed; it increases the evaporative power of the boiler, which means that two boilers with induced draught may be equal to three boilers of

the same size without such assistance. It enables thick fires to be kept on the grates, which, with a good draught, is a more economical system of firing than the thin open fires necessitated by a poor draught.

With induced draught a costly chimney is unnecessary, all that is required being a chimney for the purpose of carrying the products of combustion to a level where they will not be a source of annoyance, say from 30 to 50 feet high, according to the locality. A smaller number of boilers will develop more power, whilst the cost of the mechanical draught plant is comparatively small. A saving is thus effected both in first cost and in fuel consumption, not to mention other important advantages, such as the possibility of maintaining a uniform water gauge.

At the same time we must be careful not to adopt what may perhaps be more correctly described as forced draught. Excessive draught produces excessive temperatures, which materially increase the wear and tear, and shorten the life of the boiler. Induced draught, with a moderate water gauge of $\frac{1}{2}$ in. to $\frac{3}{4}$ in., is one thing; forced draught, with excessive pressure, is quite another.

INDEPENDENT CONDENSING PLANT.

In recent years quite a number of modern British collieries have been equipped with independent condensing plant, the idea being to provide a central condenser to deal with the exhaust from the various engines, whereby all contribute to and all participate in the general economy effected.

The great advantage of this arrangement in connection with the equipment of a colliery would appear to be in connection with the winding engines. As a general rule, a condensing winding engine is not a very satisfactory arrangement, from the peculiar character of the work which such engines are called upon to perform. Working as they do intermittently, discharging large volumes of steam with intervals of rest, the condenser directly applied could not be expected to give the results which we get from a condensing engine running for long periods under fairly regular loads.

With an independent condenser, however, this difficulty is overcome, and it is possible to work the engine with all the advantages of steam condensation.

The advantages are chiefly that we get an average of from 12 to 14 pounds per square inch increase in the effective pressure in the cylinders, which means that we get approximately one-third more work for the same steam consumption.

Several systems are in operation, each having features which render it suitable for special circumstances. In the larger central condensing plants either the jet condenser, the

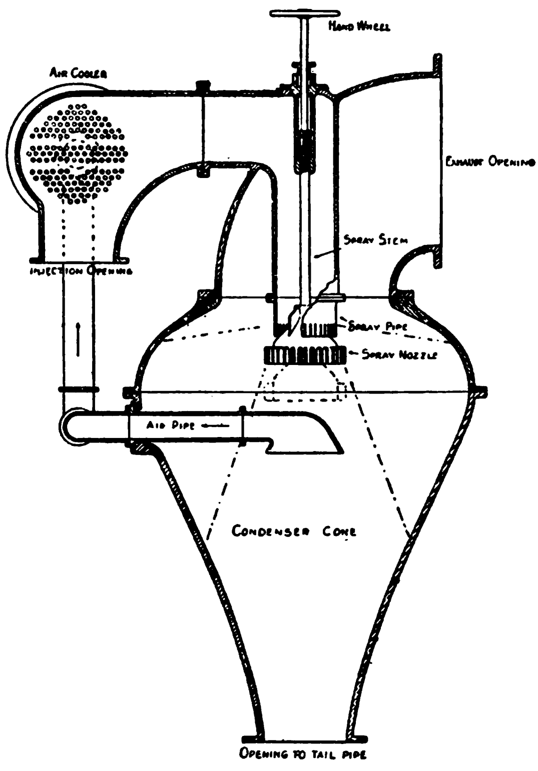


FIG. 49.
THE WORTHINGTON CENTRAL CONDENSER.

surface condenser, or the evaporative condenser is employed. In the first the steam is actually brought into contact with the condensing water. This requires a fairly large supply of water of good quality, and as a rule large cooling ponds. Where the cooling water available is of such a quality that it is desirable to keep the condensed steam separate the surface type of condenser is employed. The evaporative condenser is applicable

where water is scarce, or space for cooling ponds limited, or both.

The jet type requires from 25 to 30 pounds of condensing water per pound of steam condensed; the surface type requires about twice this quantity. The cooling surface provided in the surface condenser is at the rate of 10 pounds of steam per hour per square foot of surface.

As an example of the jet condenser, attention may be called to fig. 50, representing the arrangement made by the Worthington Pump Company.

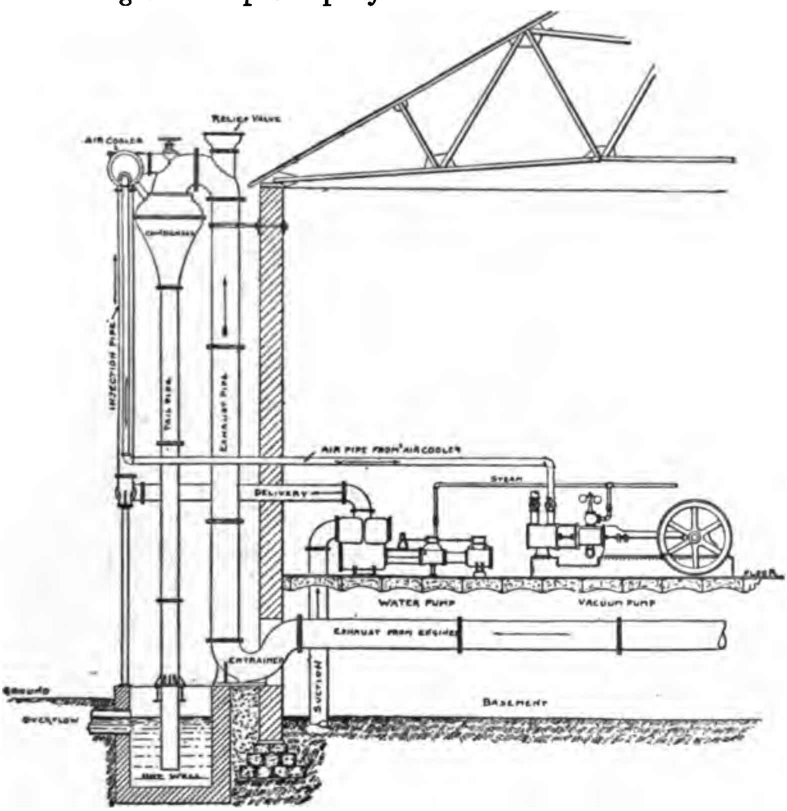


FIG. 50.
GENERAL ARRANGEMENT OF THE WORTHINGTON CENTRAL CONDENSER.

The condenser itself is shown in fig. 49. This arrangement is intended to be fixed at a height of about 30 feet above the level of the hot well, and the condensing water is forced up to this level by means of a pump, the duty of which, however, is the

difference between 30 feet and the head of water equivalent to the vacuum; in other words, the water pump is assisted in its work by the resulting vacuum obtained. As the condenser has no connection with the suction pipe of the water pump, except through the pump, it will be seen that a fluctuation or sudden fall of the vacuum in the condenser does not cause a loss of suction, as would be the case with the ordinary type of jet condenser, in which the vacuum in the condenser lifts the injection water.

This feature makes the Worthington condenser specially suitable for colliery purposes, where the intermittent working of the winding engines throws a large and sudden overload on the condenser. A separate air or vacuum pump is provided, the

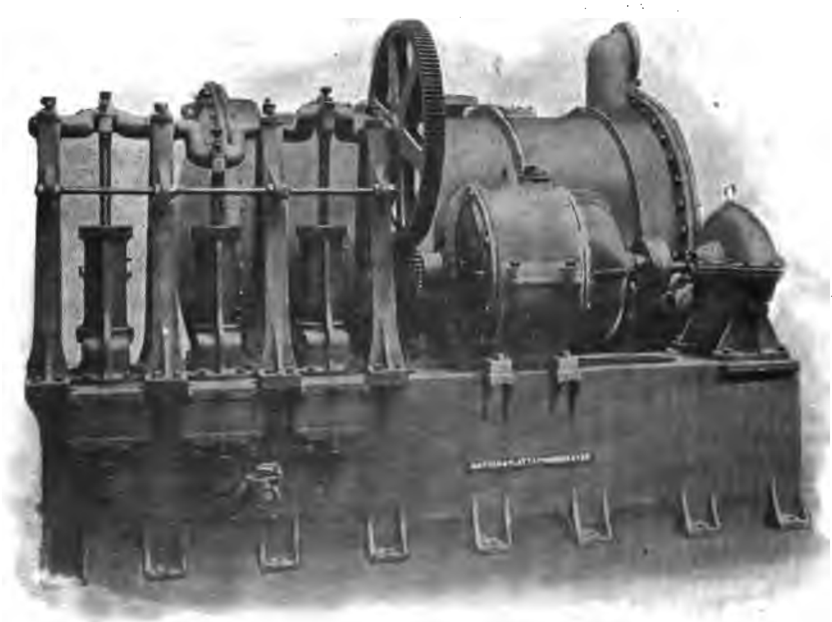


FIG. 51.

SURFACE CONDENSER BY MESSRS. MATHER & PLATT, WITH ELECTRICALLY-OPERATED AIR AND CIRCULATING PUMPS.

object of which is to remove the air which is always present in the exhaust steam, and which otherwise would interfere with the proper action of the arrangement. This air pump is of the dry vacuum type; that is to say, it pumps air only. The usual

air pump attached to a jet condenser pumps both air and water. The pipe connecting with the air pump is seen protruding into the condenser from the left, and before the air reaches the pump it passes through a cooling arrangement, which consists of a number of tubes round which the cold injection water flows, thus increasing the efficiency of the air pump. The exhaust steam from the engine enters the condenser by the large pipe on the right, fig. 49 (*see page* 89), and the injection water is delivered in the form of a well-broken stream, in the body of the steam, by the arrangement clearly shown in the illustration.

As the incoming exhaust steam and water flow in the same direction, and as the velocity of the former is imparted to the water at the point of condensation, there is no possibility of the water passing upward into the exhaust pipe, and no check valves or other automatic devices are needed to prevent the water in the tail pipe from oscillating and going over into the exhaust pipe, the velocity being in one direction and of such a speed as to preclude any such possibility.

The drawing, fig. 50 (*see page* 88), shows a general arrangement of condenser, water pump, vacuum pump, and piping. When plants are of exceptional size and operate continuously, duplicate pumps may be used, so that a portion can be shut down for overhauling.

Either the jet or surface principle of condensation may be employed, with the special advantages that belong to each. The former is to be used where good water may be had for boiler feeding, and the latter is desirable where the water is impure and the condensed steam from the engine is preferred.

A good example of a surface condenser is furnished by Messrs. Mather & Platt Limited, in the illustration, fig. 51. The arrangement shown is suitable for a total of about 2000 horse power. Larger sizes are, of course, made; but the illustration is useful as giving a good idea of the general arrangement of condenser, air pump, and circulating pump.

The surface condenser consists essentially of a cast-iron chamber, into which the steam is exhausted. Here it is brought into contact with a large expanse of cold metallic surface, taking the form of the outsides of a large number of brass tubes, through which cold water is circulated by means

of the circulating pump. The air and condensed steam are removed by the air pump.

Other examples of surface condensers are shown in figs. 52 and 53.

In connection with the surface condenser a cooling pond is

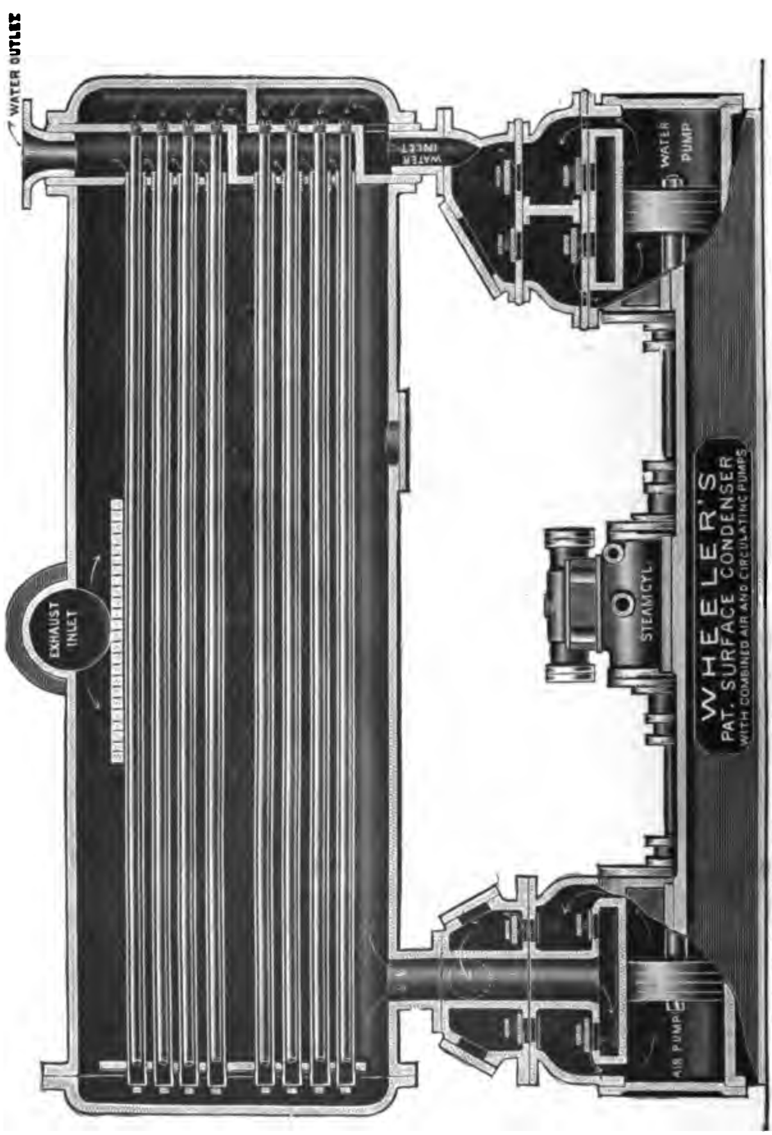


Fig. 52.

Section of the Wheeler Surface Condenser.

usually provided, but where space, or water, or both, are scarce, a cooling tower may be applied.

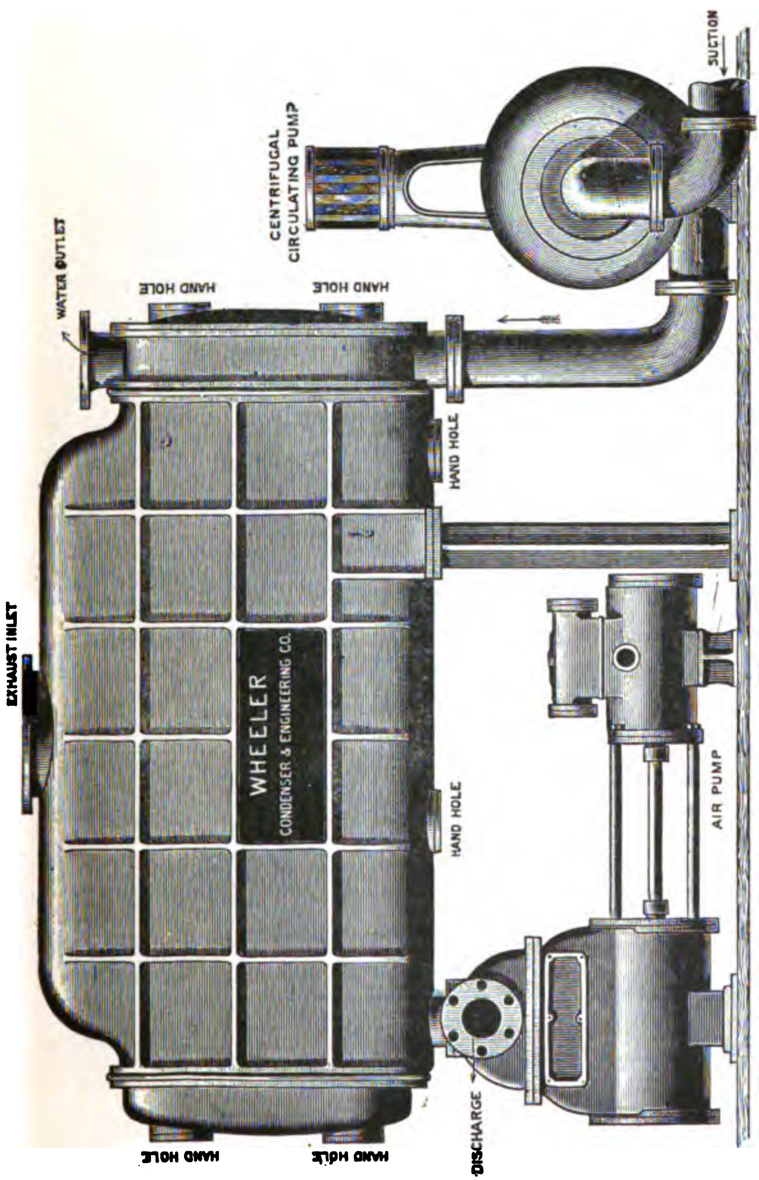


FIG. 53.
WHEELER CONDENSER.

The cooling tower consists of a tall structure of iron or wood, on the top of which the water is delivered, from whence it either falls from sprays, in the form of rain, or is allowed to

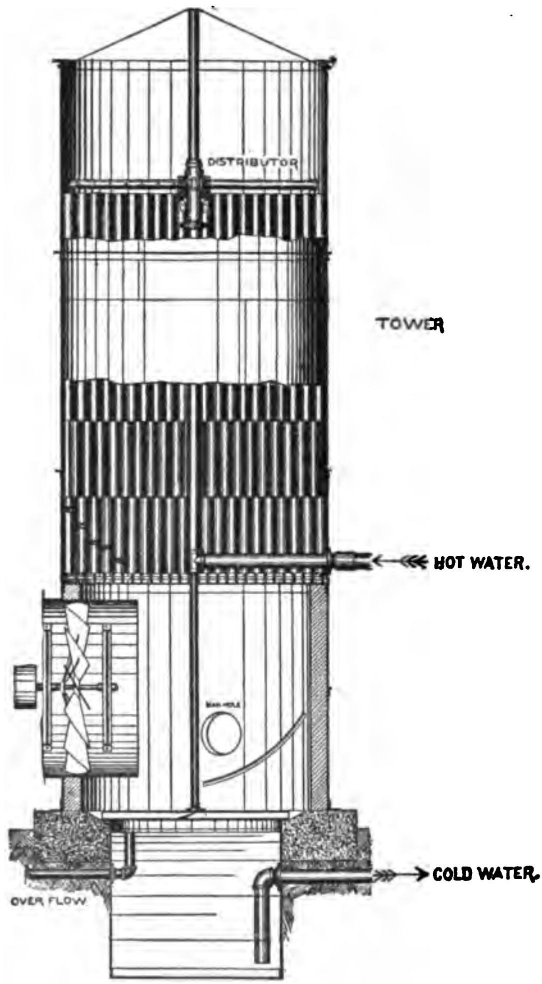


Fig. 54.
Section of the Worthington Cooling Tower.

trickle over surfaces, specially contrived, of drain tiles, thin boards, galvanised wire netting, or other suitable arrangement.

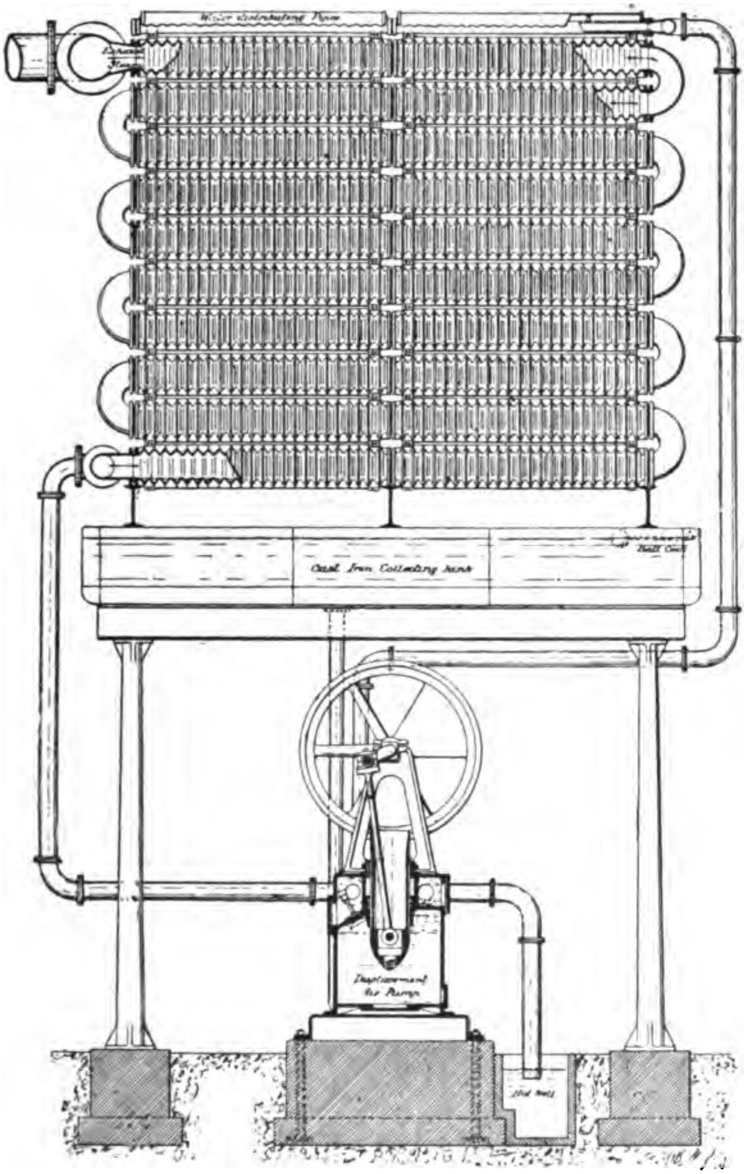


FIG. 55.

LEDWARD'S EVAPORATIVE CONDENSER.

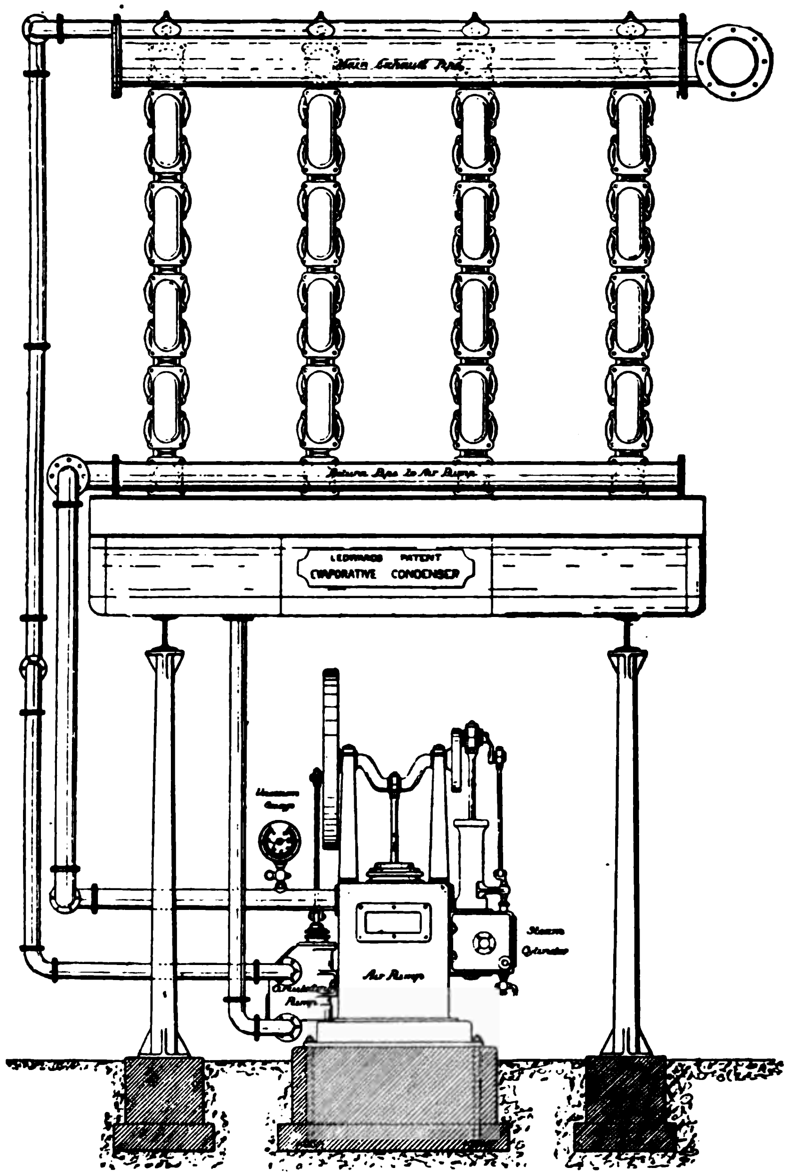


FIG. 56.

LEDWARD'S EVAPORATIVE CONDENSER.

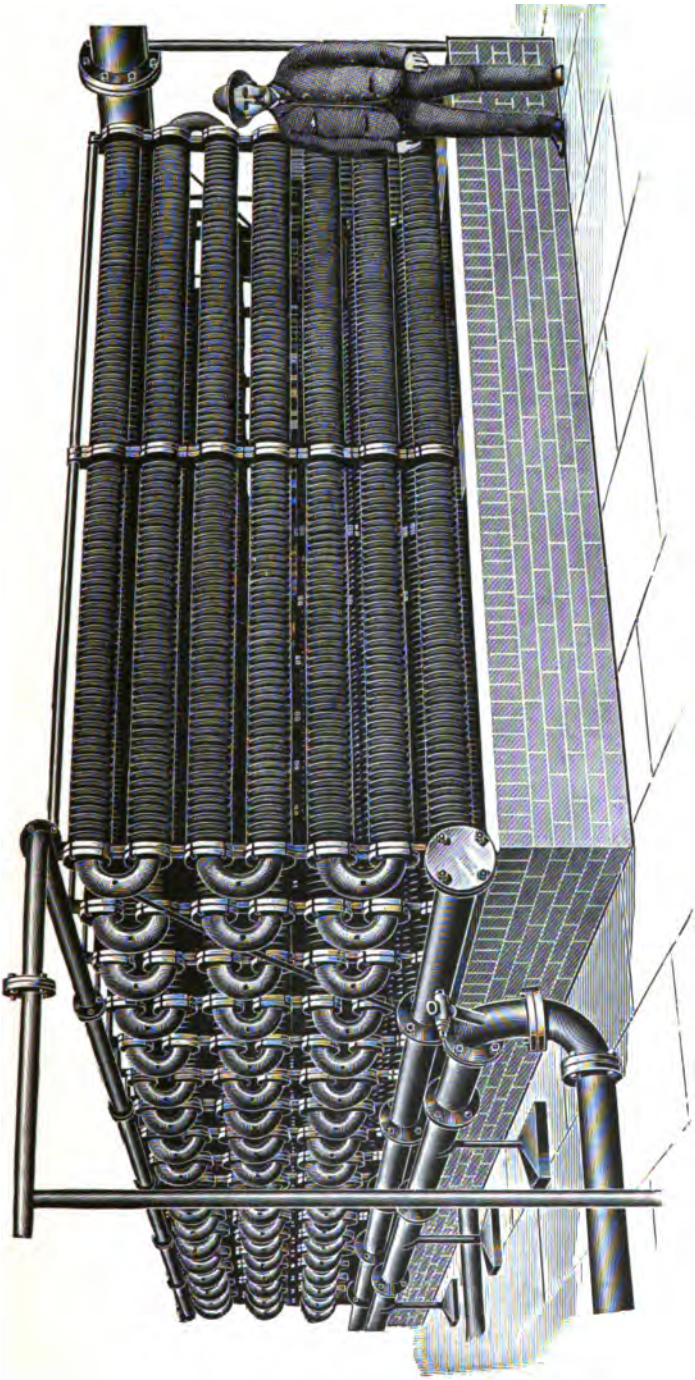


Fig. 57.
Ledward's Evaporative Condenser on Ground Level.

This, of course, takes place inside the tower, and a large volume of air, sometimes from a fan, ascends inside the tower to assist in cooling the water. (See fig. 54, *page* 94.)

Where condensation water is very scarce the evaporative condenser is sometimes used; indeed, the arrangement possesses several excellent features, which make it highly efficient. The evaporative condenser is perhaps better known as the Ledward condenser, of which two illustrations are given (figs. 55 and 56, *see pages* 95 *and* 96).

The condenser serves the purpose both of condenser and cooler. Many of these arrangements are at work, giving a uniform vacuum of 13 pounds. The evaporative condenser consists of an arrangement of gilled or ribbed cast-iron pipes, into which the exhaust steam is discharged at the top, whilst the condensed steam and air are withdrawn from the bottom. Although shown in this way in the sketch, it must be explained that the arrangement is not necessarily elevated; the stack of pipes may be built up on the ground level. (See fig. 57, *page* 97.)

Water is forced through a spraying arrangement on the top of the pipes, so that a thin film trickles over the outer surface, and as this thin film of water evaporates it absorbs heat from and condenses the steam within.

The amount of water pumped in this way, like rain, over the pipes need not be more than ten times the weight of steam to be condensed, and the weight of water lost by evaporation is not more than two-thirds of the weight of steam condensed.

FIG. 58.
A GALLOWAY BOILER ARRANGED FOR FIRING WITH BLAST FURNACE GAS

Fig. 59.
A Five-flued Boiler for Firing with Blast Furnace Gas or Waste Heat from Coke Ovens.

CHAPTER IV.

AIR-COMPRESSING MACHINERY.

DURING the progress of some of the author's earlier articles on this subject, the idea was entertained in some circles that he was prejudiced against the use of compressed air for colliery operations. The idea was absurd, because there was no prejudice, and there can be no prejudice against anything which is of value in colliery operations; but the writer is not a maker of colliery engineering appliances, and holds no brief for or against any department of colliery machinery. His aim and his duty is to guide his readers, as well as he can, as to the advantages and disadvantages of the machinery which collieries have to use. Some mining engineers have never been enamoured of compressed air, whilst others have considered that nothing could be compared to it. Our opinion is that compressed air has its useful applications, but that it is a costly and not the most convenient means of transmitting power in mines. There are not many alternative arrangements in connection with mines. Water pressure is available here and there, but the circumstances are very exceptional and scarcely worth consideration. Steam in mines was never popular, was always a great nuisance, and we may say has practically been abandoned. There is no doubt that the great rival to compressed air in mining work is electricity—dealt with elsewhere,—and we may say, once for all, that we believe that in the years to come electricity as a motive power underground will hold the field, and will eventually push aside all competitors. Compressed air has the very great advantage, which electricity cannot be said to have attained, of absolute safety. It can be taken anywhere in mines, whatever their character, and any influence outside its regular work is

beneficial. Compressed air may be used for drills, and for boring machines, and for coal cutters; it is also extensively used for driving hauling and pumping machinery, which circumstances require should be placed a considerable distance in the mine. It has also been used for underground locomotives, but not extensively.

Some general reference has been made elsewhere to air-compressing appliances, in that portion of the work dealing with the various motive powers, but it will be convenient to set out here, in simple fashion, what an air-compressing engine is and what it does. The usual type is horizontal, and, being to all intents and purposes a steam engine with something added, has a complete crank and flywheel motion. The piston rod of the steam cylinder is extended through the back cylinder cover, and has another piston on this extension working in another cylinder behind the steam cylinder. This we call the air cylinder, which takes air in from the atmosphere behind the piston and forces it out of the cylinder in front of the piston. The air enters the cylinder at the pressure of the atmosphere, and is compressed in the return stroke to such pressure as may have been fixed. What we do in each double stroke of the air cylinder is to draw in a cylinder full of air of atmospheric pressure, and in the return stroke this air, which has been enclosed in the cylinder, is compressed, it may be, to 45 or 60 pounds, or some higher pressure. In doing so, we of course diminish the bulk or volume proportionately. Now, looking at the matter simply and theoretically, if we lost nothing in the shape of work during compression, and could in using the compressed air simply expand it down to the atmospheric pressure, we should get back all the work expended in the compression, so that our only loss would be that which is incidental to the machinery, and we could certainly rely upon 80 per cent of the work being passed over from the steam cylinder. This would be admirable, and we should have at our disposal a cheap and a safe means of transmitting power in mines. But, unfortunately, air, which would appear to be an excellent medium for receiving and giving out power, is not so; and there are not a few eminent mining authorities in the United Kingdom and elsewhere who state that the useful effect of compressed air—that is to say the proportion of the work passed over from the steam

cylinder—does not exceed an average of one-third. The writer is bound to say that he places his humble opinion on the side of these authorities. Not much stress need be laid on the cost of air-compressing plant at the surface, because whatever means of transmitting power we adopt the plant will be costly so far as the surface arrangements are concerned; and even the cost of the pipes for transmission need not constitute a fatal obstacle, although the inconvenience of adapting rigid pipes to the curves and turns incidental to mines is somewhat serious; all these could be accepted if the useful effect was at all reasonable. Most of our readers now know well the causes of this great loss. Heat and work are, in mechanical matters, practically one and the same; at any rate one is interchangeable with the other. Where air is compressed heat is produced, that is inevitable; if this heat disappears it represents so much mechanical work lost, and in that practically rests the explanation of the low useful effect of compressed air. When the arrangements are bad this loss may be much aggravated, the heat generated by compression may operate upon the air itself and substantially expand the air. The mechanical work of compression is expended upon this artificial bulk, which will fall to its normal capacity on leaving the air cylinder, and whilst we have done work upon a large volume we have only a comparatively small volume to return the work. And we are hampered in another way. The reverse operation takes place when air is expanded to that which goes on when air is being compressed. In the former case heat is in evidence largely, and in the latter case intense cold prevails; the result is that to use the compressed air in the same way as steam, and cutting off at an early portion of the stroke and obtaining the benefits of expansive working, is impracticable. What it amounts to is that the pressure of the compressed air is practically uniform in the cylinders, where it is doing good work, and this cannot be economic. Further than all this, defective engines and valves, and pipes of insufficient capacity, add largely to the causes of loss; but upon this something has already been said, and more will be said later.

The writer was identified a good many years ago with some very defective air-compressing engines. An attempt was made to obtain better results by the substitution of a pair of vertical engines with beams. These engines had quite a history; they

were made by the Lilleshall Company as blast furnace engines, to produce the very moderate pressure of about four pounds on the square inch, and were exhibited at the London Exhibition of 1862. They were purchased and erected at the blast furnace works now the property of the Wigan Coal and Iron Company, and in the early days of his apprenticeship the writer assisted in the erection. Time went on, and great extensions were made at these blast furnace works, including powerful blowing machinery; this smaller pair of blowing engines were set at liberty, and adapted for the purpose of generating compressed air at 45 pounds' pressure. The services of an eminent ex-president of the Institute of Mechanical Engineers were utilised, and he placed a smaller cylinder, 20 inches diameter, within the original cylinder, 50 inches diameter; he made use of the annular space as a water jacket, and also provided for a spray of cold water to enter the compressing cylinders under pressure. The results were not satisfactory. Good air-compressing engines can hardly be built up or modified from machinery intended for a distinctly different purpose.

At a meeting of the Institute of Mechanical Engineers held at Cardiff, a paper—referred to later—was read, which produced a very valuable discussion. Sir William Siemens was present, and made, as he always made, some instructive remarks, and, although his firm was largely identified with electrical applications, he spoke very favourably with regard to compressed air in mines as providing a medium colder than the mine itself. He had experimented in the matter of transmitting power by compressing air, of cooling that air, and then letting it expand again, and he found that the attainable limit of useful effect was about 50 per cent of the power exerted in the compression. A very ingenious suggestion was made by Sir William Siemens for remedying the great loss arising from the heat expanding the air—namely, to inject cold water in the form of spray into the compressing cylinder in sufficient quantity to keep the temperature practically uniform throughout the stroke. Then, in expanding the air to do work, the difficulty of getting rid of the ice formed in the passages of the expanding cylinder might be altogether surmounted if water were injected into that cylinder at the temperature of 80 or 90 degrees, which was commonly existing at the bottom of a coal mine. This water,

imparting its heating to the expanding air, would prevent the formation of ice, and would produce precisely the same advantage as that obtained in the compressing cylinder by the injection of water, and these two savings together would very materially alter the result obtained in percentage of useful effect. The most perfect arrangement, if it could be carried out, would be to take the very same water which had been injected into the compressing cylinder and inject it again into the expanding cylinder, so that the heat taken from the air during its compression should be restored to it during its expansion. By that means, if the quantity of water injected were such as to keep the temperature practically uniform throughout the stroke, the whole of the loss at present arising from the heating and cooling of the air would be avoided, and there would be no loss of power beyond that due to the friction of the machinery and the pipes. Sir William Siemens was no mere theorist, and few men did better engineering work, and it is no reflection to say that this was a pretty proposal which has not been put in operation, and is not likely to come into the domain of practice. The writer often thinks of Sir William Siemens in connection with the movement for producing gas on a great scale for motive power. In the last quarter of the nineteenth century, and early in that quarter, Sir William Siemens delivered an admirable popular lecture to the working men of Bradford in connection with the meeting of the British Association. His subject was "Fuel," and he mentioned another beautiful ideal of his—namely, to convert the coal into gas in the mine itself, to pipe that gas to the surface, and transmit it over the land to be used for all the purposes for which coal in its solid condition is utilised.

The last-named proposal is not more likely to come about than the former, and one is almost forced to the conclusion that Sir William Siemens, who had probably an engineering talent—civil, mechanical, electrical—second to no man of his time, lacked special knowledge in that branch of engineering relating to mining. We are not likely to see, during the twentieth century, the establishment of great gasworks in the bowels of the earth. If such a system was attempted, the disasters to which we have been too much accustomed would be as nothing, and accidents in mines under such a condition of things would assume the magnitude of earthquakes.

Not the least interesting part of the paper was the result of experiments to determine the useful effect, and there is clear evidence at any rate that the results were fairly stated. To obtain compressed air at 40 pounds per square inch above the atmosphere, the useful effect was 25·8 per cent; for 34 pounds, a useful effect of 27·1; for 28½ pounds, a useful effect of 28·5; for 24 pounds, a useful effect of 34·9; for 19 pounds, the useful effect was 45·8. No doubt our readers quite understand that the useful effect of compressed air diminishes as the pressure of that compressed air increases. The useful effect obtained from compressed air at 40 pounds' pressure was ascertained to be 25 per cent of the power developed in the steam cylinder when working with 28 pounds of steam in the cylinder, continued for nearly seven-eighths of the stroke; and we are told that the percentage of useful effect would be substantially increased by the use of steam at 70 pounds' pressure, cutting off at quarter stroke. There is no doubt that more work would be got out of the steam by using it at a high pressure, and with a fairly high range of expansion, but it was not made quite clear that taking a certain indicated horse power as generated in the steam cylinder, why we should get a larger measure of useful effect in the air cylinder. The fact is, that this particular paper was probably the best up to its time of delivery that had been given on air-compressing machinery, and led to a most useful discussion, at which the writer had the pleasure and benefit of being present, and it came as a smart surprise in many quarters to have it demonstrated by an elaborate series of experiments that the useful effect of compressed air could approach anything like so low a figure as 25 per cent of the power generated in the steam cylinder. The particulars, however, did much good, and whilst removing some false impressions prevailing in certain quarters as to what compressed air was capable of, it paved the way for improvements which enabled designers afterwards to make a somewhat higher useful effect possible.

In the matter of ice formation, and the means of prevention, a mining engineer with much experience in coal-cutting machines mentioned that a great difficulty experienced by him in the use of compressed air was this stoppage of passages by ice formation, and so serious was the difficulty that the machine had to be stopped each now and again to allow the ice to be melted. His

remedy was to make all the passages through which exhaust compressed air had to be delivered of greater capacity, and the remedy was effectual. Another authority advocated, for overcoming this difficulty, the use of large valves and large passages. The injurious influence arose from moisture in the air. That was news to us at one time, but we are all aware now that the best preventive of the freezing in air-compressing appliances is to have the air dry; it is the moisture, of course, which forms the ice, not the air. A direct discharge for the exhaust was also advocated, because it is in curves, and bends, and turns where mischief is so liable to arise. A further means of getting warmth to the cylinder by casting on it a series of radiating wings was suggested as likely to effectually take up the warmth from the atmosphere in the mine, and keep up the temperature of the air cylinder sufficiently. It may be interpolated here that whatever method or methods we adopt, we should avoid the application of heat direct by means of lamps. One case at least is on record in which a torch lamp was so applied, and oil and waste, and other inflammable *débris*, being rather too abundant, the mine got on fire.

An interesting comparison was made during the discussion as between the transmission of power by compressed air and by water pressure, and the friction resulting therefrom. It must be remembered that at the time to which we are addressing ourselves, the really serious rival to compressed air had not entered the field. As an abstract fact it was, of course, true that there was less friction in the passage of air through pipes than arose from the flow of water through pipes. But this did not make it so simple in a practical application, taking into account the difference in the pressures that would be employed in the two cases. In the use of compressed air the usual working pressure had not then much exceeded 40 pounds per square inch above the atmosphere, and it was just as common to use water pressure as high as 700 pounds. Taking air at 40 pounds' pressure and water at 700 pounds' pressure, it was clear that in order to get an equal power out of an engine it would be necessary to use 17½ times as great a bulk of air as of water, and the velocity of the air through the pipes would have to be 17½ times as great as the velocity of water through the same pipes. Hence, provided the density of the air and the water were the same, the

skin friction, being as the square of the velocity, would be 306 times that of water, and as there was also 17½ times greater bulk to deliver, the power required to overcome the velocity would be as the cube of the velocity, or 5359 times the power required with water. But the friction varies directly as the density, and air at 40 pounds' pressure above the atmosphere being about 220 times as light as water, these figures must be divided by 220, which give as the practical result 1·4 times greater friction and 24 times greater loss of power with air than with water. That was the result with pipes of the same size, but it was evident that by increasing the diameter of the pipes used for the transmission of air, and thereby reducing the velocity, the relative loss of power from friction would be reduced to a very large extent. Still, it was thus seen that in practice there was far more loss of power in transmission of that power by air than by water. This is not presented as advocating the application of water pressure in mines, because, unless the water pressure is available in any case, no one would think of turning water into a mine to drive machinery; every pound of water so turned in would necessitate more mechanical work to get it out again than the mechanical work that it possibly could be capable of. It is presented for the simple purpose of showing that on every side the use of compressed air is attended with cost, and causes present themselves showing why there can be no such desirable result as a high useful effect.

Compressed air has been a good deal used in the driving of tunnels, and one of the longest tunnels in the world is the St. Gothard. The motive power was available by water at both ends of the tunnel, and the question of economy, in consequence, in the generation of the compressed air had scarcely to be considered. The water power was communicated to turbines, and these worked the compressors, the former being vertical and the latter horizontal. The diameter of each air-compressing cylinder was 19 inches and the stroke 17 inches, and the average piston speed was 266 feet per minute. Each set of three air compressors delivered 141 cubic feet per minute compressed to eight atmospheres, being equal to 105 pounds per square inch above atmospheric pressure. A remarkable feature of this air-compressing installation was that, although as work went on the

air had to be transmitted a distance of several miles, the loss of pressure was scarcely worth mentioning, showing the excellence of the capacity of the machinery and the means of transmission from the air compressors to the drills.

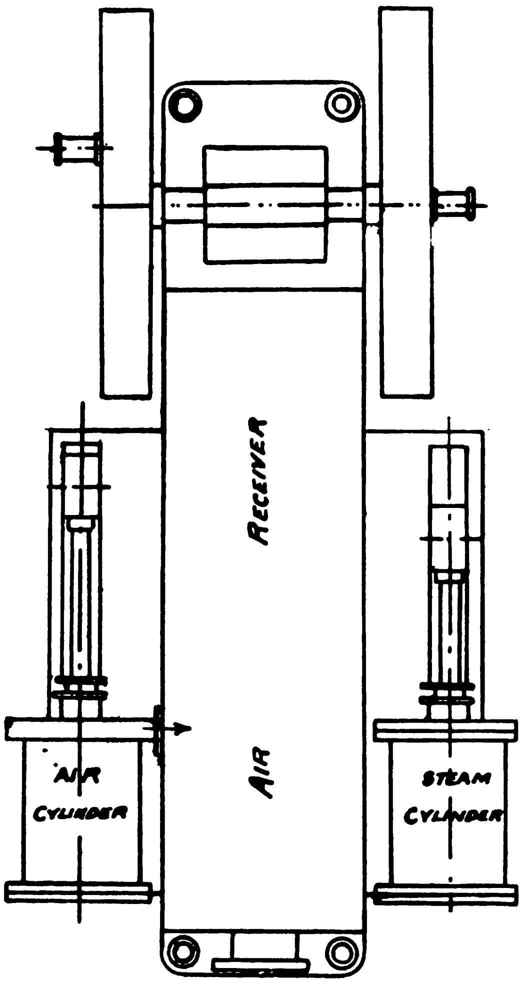


FIG. 60.
PLAN OF STURGEON'S COMPRESSOR.

Figs. 60 and 61 (*see page* 111) represent the Sturgeon air compressor, which held a somewhat peculiar position amongst air-compressing machinery, because it worked at a high speed, and it was claimed for it that it produced a higher useful effect than the ordinary air compressor. The inlet valves were

entirely different in their mode of operation from such valves generally. A common arrangement has been to place these inlet valves in the covers of the air cylinder, and to allow the valves to open under the influence of a slight vacuum produced by the forward stroke of the piston, and to close immediately the return stroke commenced under the influence of pressure within the cylinder; that, we may venture to say, is not unlike the system still in operation in the case of many air-compressing engines at work. In the Sturgeon air compressor these inlet valves actually formed part of the stuffing box upon the piston rod, and are made to open and close by their grip of the rod compelling them to move. (*See fig.* 61.) This early endeavour at mechanical control of the valves hardly impresses one—the objections would seem to be that the action would hardly be quick enough, because although the compressor worked at a high speed the portion of the stroke before the valve closed would be the same as if the compressor worked at a less speed, and one would rather expect that in time the valve would work loose upon the rod,—but it was said that the arrangement worked well. Unless there is an effective method of operating the valves, what was called high speed in air compressors was hardly likely to commend itself, because it is no use the engine outrunning its own valves, and anything like an excessive speed would almost seem certain to lose a portion of each stroke. The writer has, perhaps, leaned rather too much to what may be called moderate speeds, and, unless with the assistance of exceptional arrangements, he is still inclined in that direction. Sturgeon was a very ingenious engineer, and the writer made his acquaintance in his early days, in the coal-cutting experimental era, because Sturgeon was interested in coal-cutting machines as well as air compressors. In his arrangement of air compressor he had an ingenious mechanism, which seemed to take the place of a governor, and did its work successfully. On the flywheel shaft there was an eccentric, and by connection with a combination of levers, actuated the valve of the steam cylinder in such a manner as to lengthen or shorten the travel, according as more or less work was being done, and more or less air was being required. This was no doubt one of those simple applications of automatic expansion gears of which we were to hear much more in the years that

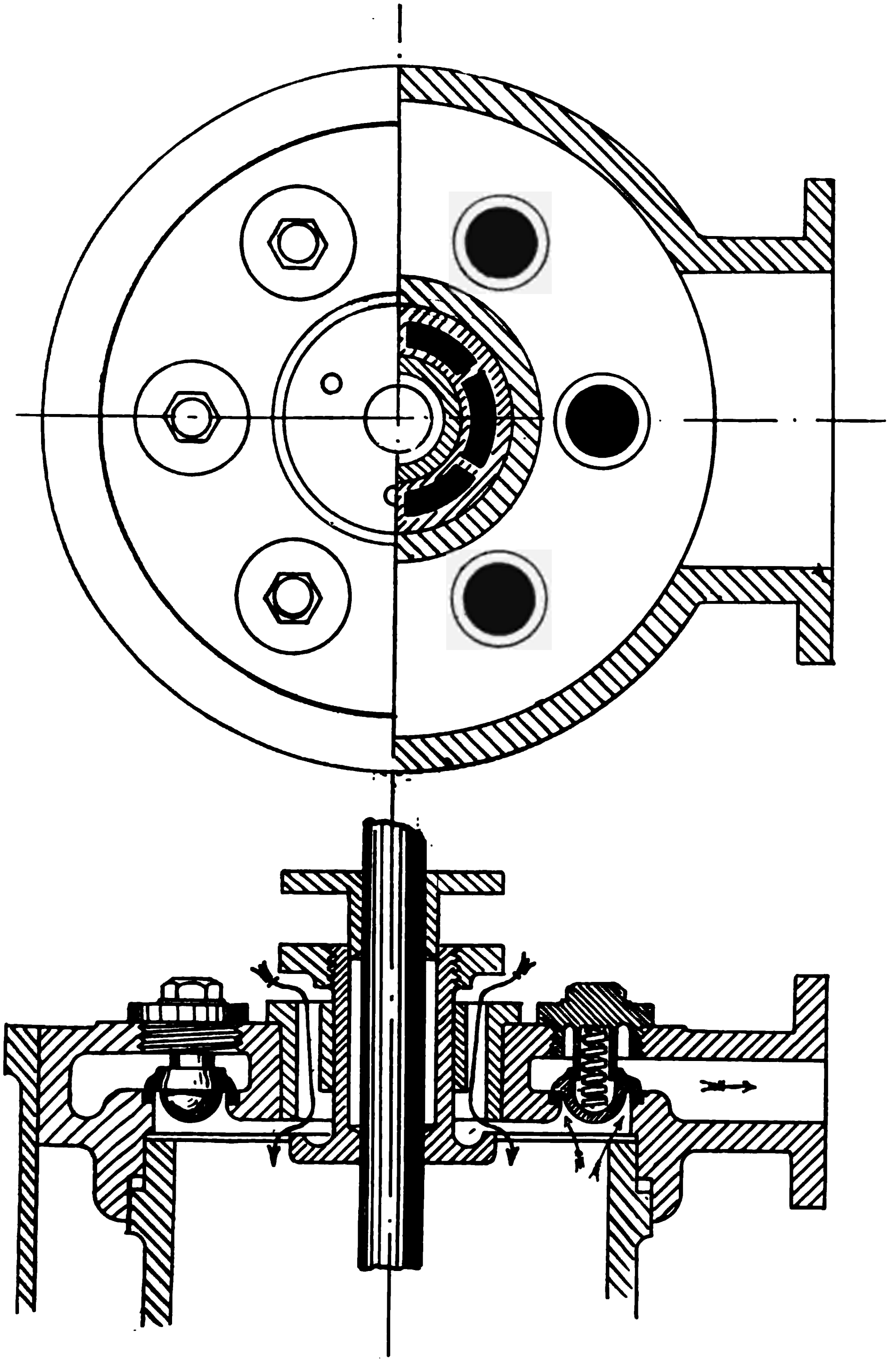


FIG. 61.
SHOWING THE INLET AND DISCHARGE VALVES.

followed. The Sturgeon air compressor was a single engine, which, as our readers know, we do not like, but it was superior to the ordinary single engine. The air and steam cylinders were not in line, with one piston rod answering for both pistons, but by placing the air and steam pistons in connection with separate cranks fixed at right angles, the steam piston was made most effective; that is, its crank is at full throw when

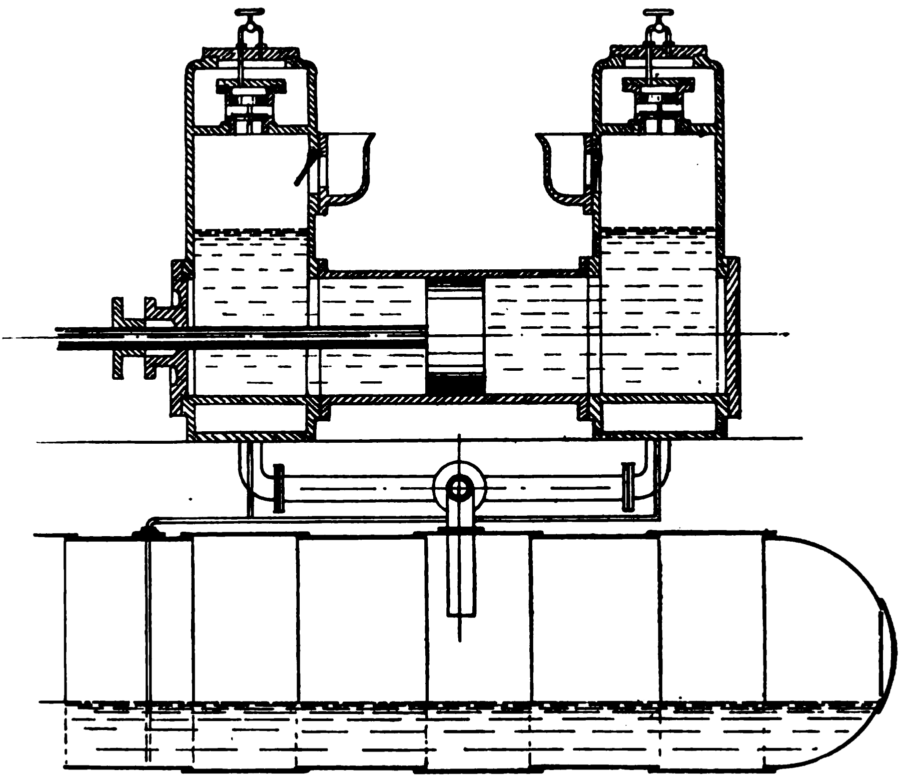


FIG. 62.
THE WET AIR COMPRESSOR.

the work upon the air piston is greatest—namely, when the stroke is about being completed. This principle might be applied to all single air-compressing engines, otherwise the possible expansion of the steam is very limited. The Sturgeon air compressor is a very compact piece of machinery, having the receiver into which the compressed air is delivered between

the two cylinders, and there is a good flywheel upon each side. It runs with much steadiness—its high speed will help that,—and little foundation is required, as it is well balanced, and the strains are equally distributed.

Fig. 62 represents the wet air compressor, which attracted a good deal of attention, and although it has not taken that position at the head of good air-compressing machinery that most of its supporters hoped and anticipated, it has done good work, and is of sufficient interest, even in the present century, to deserve somewhat full reference in these pages. The appliance would appear to have had its introduction in the United States of America, and its object was to fill up what would otherwise be clearance capacity by water, which moved to and fro with the piston, and any excess of water was simply driven back out of the cylinders into the source of supply, and was available again. This clearance capacity is a very serious matter in the compression of air, because suppose we are compressing the air to five atmospheres, an inch long of clearance represents five times that length of cylinder capacity. Suppose our stroke is five feet, we compress the air into one foot, and for each inch long of clearance capacity we lose one-twelfth of the compressed air on which full work has been done. Some of our engineers tell us that this clearance capacity is not really a loss, because it helps the piston back; but surely such misguided men might know that work is thus needlessly expended upon a certain volume of air again and again, reducing the effective capacity of the compressor, since this air, although compressed, is not delivered into the receiver or pipes.

The water in these wet air compressors, provided it was continuously being renewed, materially assisted in taking up the heat. Our distinguished friend, Mr. W. E. Garforth, gave this class of air compressor greater opportunities than any other engineer, and he was good enough to furnish the illustration referred to. There was nothing special in connection with the inlet valves, but the outlet valves were of special construction and arrangement. Each valve and seating was made of gun metal, with an arrangement by which the compressed air acted as a cushion. The upper portion of the valve chamber was carried outside the main tower, and by means of a valve the compressed air within the chamber could be regulated at

pleasure. These valves required little power to lift, and the saving of wear and tear was considerable. The air-compressing cylinders were always filled with water, also the tower, at the termination of each stroke, so that no air was lost by churning. At each stroke a small quantity of water was forced through the outlet valve, thus proving that no air remained. The outlet valves also served the purpose of safety or relief valves for the surplus water. The cylinders were kept cool by the constant charge of cold water, consequently the power which requires to be exerted at an earlier part of the stroke by reason of the expansion of air due to the hot cylinders and dry process was thus saved by the wet system of compression. The feed pipes were regulated by separate valves near the feet of the air cylinders, and they extended from the bottom of the receiver into the clylinders. The tops of these pipes, where they entered the air cylinders, were fitted with nozzles, which split up the water and formed a spray to cool the incoming air. The results proved that, at low and moderate speeds, the system was satisfactory; but for high speeds, and even less than what we should consider high speeds at the present day, the system was practically inoperative. The limit of piston speed seems to have been 275 feet per minute, and really, if excellent results were obtainable up to that speed, it would hardly seem to matter much to aim at a higher speed; the majority of air compressing engines, even yet, do not work at a greater piston speed than 275 feet per minute. As might have been expected from those in charge of the experiments, every care was exercised to pass the air in as cool as possible; also there was full recognition that the pipes transmitting the air should be of sufficient capacity—namely, eight inches diameter; and although the distance of transmission was a mile and a half, the loss of pressure was scarcely within recognition. The receivers close to the air-compressing engines into which the engines delivered their compressed air were large, and the result was that any moisture had every opportunity of collecting at the bottom, and the pressure for transmission was kept uniform. The air receivers in front of each engine or machine in the mine to be worked were also fairly large, and the result was that, as the moisture had liberated itself from the air, there was no freezing, because there was nothing to freeze. The question

might be asked, What is a suitable size of air receiver? There is no intention to offer any mathematical solution of this problem, but it might be accepted as a fairly practical rule that the air receiver capacity adjoining the air-compressing engines should be at least equal to the volume which the air compressors will deliver in one minute. There is not the same necessity for capacity in the air receivers placed in front of each engine or machine to be driven by compressed air, and probably a capacity representing the supply for half a dozen double strokes would be reasonably ample. The air would, of course, enter the air receiver and leave it on the higher side, and whilst the delivery pipe might dip, say, half-way down the receiver, the pipe taking the air out of the receiver could with advantage be kept well up.

The writer finds, in looking over his early notes, some figures taken from French authorities with regard to loss of pressure at certain velocities—namely, from 3·28 to 19·68 feet per second—through pipes of different diameters—namely, from four inches to fourteen inches. The sizes of the pipes are reasonable, because we should seldom have less than four inches diameter and seldom greater than fourteen inches diameter, the experimental length being 3280 feet. But the pressure entering the pipes does not seem to be mentioned; and as to the velocity of the air, the maximum given, namely 19·68, is very low—the possible speed of compressed air in pipes, without injustice to the operation, the writer has taken as high as 100 feet per second. However, we will not give the figures, but simply mention one or two results. In a four-inch pipe the loss of pressure in pounds per square inch was ·114 at the minimum velocity and 4·446 at the maximum velocity, being practically an increase of forty to one with an increased velocity of about six to one. With the fourteen-inch pipes the loss was ·038 at the minimum velocity and 1·280 at the maximum velocity, being an increase in the loss of about thirty to one. What it would really seem to mean is, that the loss of pressure will increase as the square of the velocity, and diminish as the area of the pipes increases. So that supposing we had two systems delivering the same volume of air, and that our pipes were respectively six inches and twelve inches diameter, the velocities would be one in the twelve-inch and four in the six-inch pipe; the friction

under the head of velocity would be sixteen in the six-inch pipe and one in the twelve-inch pipe; so that the total resistance would be thirty-two in the six-inch pipe and one in the twelve-inch pipe. Of course, this strikes us as very great; but provided the pipes were sufficiently large at six inches the loss would be inconsiderable, and although a larger pipe would diminish the loss there is a limit, and the basis should be that a pipe for the transmission of compressed air should be such that the linear velocity of the air through the pipe will not need under any circumstances to exceed one hundred feet a second. There seem to be some other figures, giving the loss of pressure in a uniform length of five hundred feet of air entering the pipes at five atmospheres, and through pipes of different diameters, and although the velocity of the air is not given the volume is stated. Taking the first group of pipes, three inches, four inches, and five inches, we find that the loss to deliver forty-eight cubic feet per minute was ·023 pound per square inch in the three-inch pipe, and when the same pipe delivered eight times as much air the friction was sixty-four times as great. In the five-inch pipe the quantity delivered was 134, and the loss was ·014; the same pipe delivering ten times as much air increased its friction one hundred times. The six-inch pipe delivered 193 with a loss of ·011, and delivered ten times as much with a loss one hundred times as great. The ten-inch pipe delivered 537 cubic feet per minute at five atmospheres, and the loss was ·007 pound per square inch; the same pipes to deliver ten times as much air incurred a loss one hundred times as great. Experiments showed that for a given diameter of pipe the loss was in proportion to length, so that we have arrived at this—that friction of a given pressure will vary directly as the length of the pipes through which the transmission takes place, will vary as the square of the velocity of the air in the pipes, and will vary inversely as the area of the pipes; so that in working out these calculations we have a twofold problem—namely, that connected with the velocity and that connected with the diameter. The figures are none the less interesting as showing—the volume being worked out into linear velocity—a speed in the higher quantity of the ten-inch pipe very much higher than that which the writer makes his basis. The loss for each five hundred feet of length would seem to be three-quarters of a

pound per square inch, which for a mile of pipes would be 7½ pounds, and is considerably higher than one would be content with. But the velocity is very much greater than the writer's basis, and when we get beyond the maximum of one hundred feet per second, other conditions operate both with steam and air, and increase the resistances more rapidly. But even on the ordinary lines the velocity of the figures is 166, and the maximum velocity of the writer is 100; the difference in the squares is as 2½ to 1, and 7½ divided by 2½ equals three pounds per square inch loss for each mile, which would be very different, and would not be considered unendurable.

No writer on colliery engineering could, with credit to himself or justice to his readers, which is the chief consideration, avoid reference to what has been done, and is being done, by Messrs. Walker Brothers, of the Pagefield Ironworks, Wigan, and the remark applies to their productions in air-compressing machinery. The writer would be sorry to ever appear to depreciate what so many excellent colliery engineering firms are accomplishing. There is room for us all, although, perhaps, not in this particular work, and it is not unfortunate to be able to give so admirable a type of British colliery machinery makers. The writer has followed the career of Walker Brothers from their commencement in the sixties of the last century. Electricity was not available then, and the motive power adopted was compressed air. We have shown what crude and ill-designed air-compressing engines were available then. Walker Brothers applied themselves to remedy the defect. Their success has been very great, and certainly not greater than their deserts. An aggregate total of nearly a quarter of a million of indicated horse power and over 550 installations speak more eloquently than any remarks of the writer could do.

The general design of the air cylinders and valves has always been, and was bound to be, a particular feature; that is a perfect valve for an air compressor which opens with ease when it should, and closes with ease at the proper time. Walker's valves are of that character that they actually cover what would otherwise be wasteful clearance capacity. When the valves are closed they so fill the openings as to present a perfectly flat surface on the interior of the cylinder covers.

So exact is the arrangement that the valves and covers almost touch the piston at each end of the stroke. The inlet valves are designed so that ample opening is obtained the moment the piston commences its stroke, and they close immediately the piston has completed its stroke. The outlet valves are free to adapt themselves to the increasing or decreasing pressure of air inside the cylinder. There is no perceptible difference in the time of the opening of the inlet valve and the closing of the outlet valve. By a patented means of adjusting the valves, which includes the application of a moderate elastic pressure for balancing the valve as suspended on its hinge, and by an externally-applied indiarubber buffering apparatus on its closing, the valves work either at slow or at the highest velocities in a perfect manner. About one-third of the area of the cylinder covers at each end is given to the inlet valve, and about one-third to the outlet valve. The valves being suspended at the top, as on a hinge, close by their own gravity, and, being of large dimensions, a small lift only is required to afford the necessary opening. There is one inlet valve and one outlet valve only at each end of the cylinder for all sizes of compressors. But Walker Brothers have not been content with good air-compressing cylinders, but they have exercised great talent in the designing and construction of the steam engine portion of the installation. Their steam engines are compound and condensing, essentials to all good steam engines. The latest departure in connection with the production of compressed air has been in the introduction of what is called stage compression. There is nothing new in the idea—is there anything new under the sun? The idea was suggested to the writer a long time ago, by one who had done much in endeavouring to utilise compressed air to advantage. By stage compressing we mean that the operation is divided into two stages. The air is compressed first in a low-pressure cylinder, thence passing to what we call the intermediate cooler, which is a vessel after the form of a surface condenser, and cooling circulation water within the tubes has its effect upon the compressed air surrounding the tubes. Then the compressed air passes from the intermediate cooler into the high-pressure cylinder. The aim is this—we have tried to show that the higher the compression the greater the generation of heat and the greater the loss of power.

By dividing the operation there is less production of heat in any one cylinder, and the intermediate cooler is invaluable. We present an outline specification of Walker's air-compressing engines.

OUTLINE SPECIFICATION OF MESSRS. WALKER BROTHERS' AIR-COMPRESSING ENGINES.

The steam cylinders are cast of strong close-grained metal, as hard as can be readily bored and planed. The covers are turned and polished. All the glands are bushed with brass. The valves are on the slide principle, and are fitted with variable expansion gearing when required.

The air cylinders are fixed on a line with the steam cylinders. Each air cylinder is partially encased with metal plates, or a circular jacket, forming a cistern for cold water to prevent overheating. The air cylinders and valves are so arranged that practically all the compressed air is expelled from the cylinders. The air cylinders are fitted with our patent valves. The air valves are of steel. The pistons are of cast iron, with packing rings of similar metal. The piston rods are of steel. The piston rod caps and crossheads are of hammered iron, turned and polished. The eccentrics are of cast iron, held on the shaft by keys of steel or hammered iron. The eccentric rods are of hammered iron. The slides are of approved design, accurately planed and scraped on the sliding surfaces. The bottom slides are flanged or dished to prevent any waste of oil. The connecting rods are of hammered iron, forged in one length without weld. They are fitted with all necessary brass steps, gibs, cotters, and safety screws. The rods are machined and polished all over. The crank shaft is of hammered iron; the journals for the same are of ample dimensions. The pedestals, or plummer blocks, have heavy steps of the best selected brass. The foundation plates are of cast iron, and of approved design. They are strengthened throughout by crossbars and ribs, and well bossed at the holding-down bolts. The flywheel is of cast iron, and securely fitted to the crank shaft. A suitable steam stop valve is provided, together with the screwed ends and nuts of the holding-down bolts. We supply the same pipes connecting the two steam cylinders. The engines throughout are of the best materials and workmanship.

The Walker compressor illustrated in fig. 63 is a compound steam two-stage compressor. The engine is of the Corliss type, and is fitted with speed governor and air-regulating apparatus. The steam cylinders are 22 inches and 37 inches

FIG. 63

A TWO-STAGE AIR COMPRESSOR BY MESSRS. WALKER BROTHERS, WIGAN.

diameter, and the air cylinders 35 inches and 22 inches by 4-foot stroke.

CALCULATION FOR SIZE OF AIR COMPRESSOR.

A single example will suffice to indicate, on general lines, the manner in which one may roughly estimate the size of an air compressor required for supplying power to a number of engines underground. Of course, it will be understood that any calculation of this character is only useful as giving a general idea as to the size of the compressor. Various types of machines differ somewhat in details which affect the actual size, and in actual cases one would prefer to submit to the makers the whole requirements, and consult them as to the particular dimensions of the compressor.

Take the case of two hauling engines, one with a pair of 15-inch cylinders, 2-foot 6-inch stroke, working at 70 revolutions per minute; the other 12 inches diameter by 2-foot stroke, working at 80 revolutions, both supplied with air at 60 pounds. 15 inches equals 1·25 feet diameter equals 1·227 square feet area; multiply by 2 (for two cylinders) equals 2·454, multiply by the piston speed in feet per minute (*i.e.*, 2 feet 6 inches by 2 by 70 equals 350 feet per minute), 2·454 by 350 equals 858·9, say 859 cubic feet per minute at five atmospheres, or 4295 cubic feet per minute of free air. Similarly for the smaller engine. Area of each cylinder equals ·7854 square feet, multiply by 2 and by the piston speed, 320, equals 502·656, say 503 cubic feet per minute at five atmospheres, or 2515 cubic feet per minute of free air, making a total of 6810 cubic feet of free air per minute.

Now, assume a piston speed of, say, 400 feet per minute for the compressor; there will be two air cylinders which must give 3405 cubic feet per minute free air capacity each. 3405 divided by 400 equals 8·5 square feet area each cylinder, or 1224 square inches, which as nearly as possible works out to 40 inches diameter of the air-compressing cylinders.

From what has been said in the earlier pages of this section it will be seen that compressed air, with all its advantages, is seriously handicapped as a means of economical power transmission by circumstances entirely beyond the control and skill of the engineer, at least so far as its application in colliery operations is concerned. The generation of heat cannot be

avoided in the operation of compressing, and the most perfect cooling arrangements merely absorb this heat, which, after all, represents portion of the energy developed in the steam cylinder.

The diagram given below (fig. 64) is intended to show at a

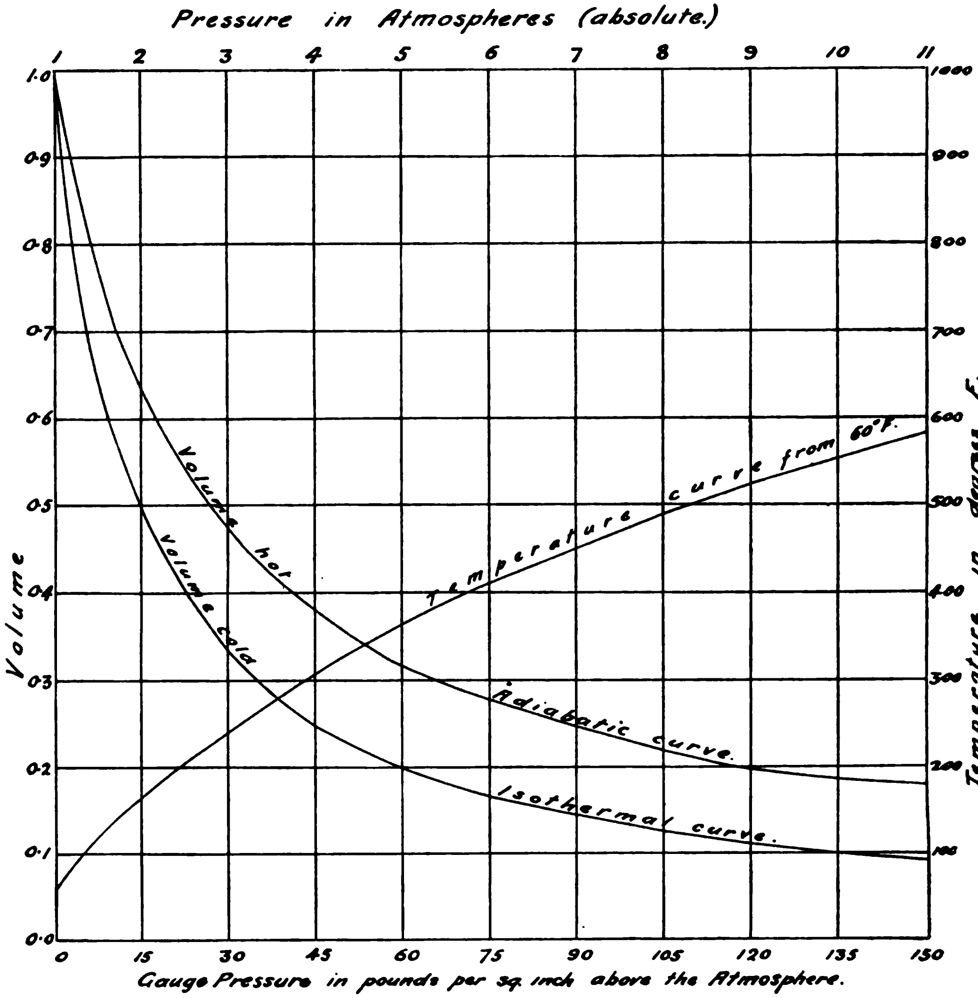


FIG. 64.

glance the volume, both at constant temperature (the isothermal curve) and the volume due to the temperature produced by

compression without cooling (the adiabatic curve), these being the curves commencing at the top on the left, and sweeping down towards the right-hand lower corner. The curve which starts near the lower left-hand corner, and curves upward towards the right, shows the temperature resulting from compression without cooling, assuming an initial temperature of 60 degrees.

Along the top of the diagram the figures attached to the vertical lines represent the absolute pressure in atmospheres, and at the bottom of the vertical lines the corresponding gauge pressure, or pressure above the atmosphere, in pounds per square inch is given, the pressure of one atmosphere being taken at 15 pounds.

Reading up the right-hand side, at the ends of the horizontal lines, are the figures representing the temperature in degrees F., whilst the opposite end of the horizontal lines, at the left-hand side, are marked to indicate the volume relatively to an initial volume of unity.

Thus air compressed to five atmospheres absolute, or 60 pounds per square inch above the atmosphere, when cold, occupies 0·2 of its original volume, and, starting from 60 degrees F., the temperature attained before cooling would be about 360 degrees F. and the volume 0·32. If the amount of compression is 150 pounds the temperature reached without cooling is about 575 degrees F.

This diagram shows, for instance, that in compressing to, say, 60 pounds without cooling, 1000 cubic feet of free air, the volume becomes, in the first instance, 320 cubic feet; but as this volume cools down to 200 cubic feet at the initial temperature, the pressure drops to little more than half of 60 pounds. This shows the importance of cooling during compression, and also the advantage of stage compression with inter-cooling. A good compressor, with proper cooling, would probably give a curve about midway between the isothermal and the adiabatic curves shown in the diagram.

There is the further difficulty that the engine worked by compressed air cannot be worked expansively, consequently at each opening of the exhaust a cylinder full of high-pressure air is discharged into the atmosphere, air which is under pressure and upon which work has been expended.

In spite of these difficulties, however, remarkable progress has been made in the development of air-compressing machinery in recent years, doubtless the result of healthy rivalry and stimulating competition.

For many years compressed air held the field alone as a means of power transmission in mines; there is now a formidable rival in the arena—electricity, and the fight will be a good one and one productive of good.

The principal developments have been in the direction of what is called stage compression, and improvements in the valve arrangements. In stage compression the air is dealt with in two or more cylinders successively, a moderate amount of compression being effected in each stage with intermediate cooling. Two-stage, three-stage, and even four-stage compressors are in operation, the final pressure being much higher than has been the practice in the earlier types.

COMPRESSING IN TWO OR MORE STAGES.

The tendency in recent years for higher pressures has led to the general adoption of two and three-stage compressors, in order to reduce to a minimum the losses incurred through the high temperature attained in compressing to a high pressure in one operation. The general idea in, say, two-stage compression—and anything higher than 60 pounds should certainly not be attempted in one stage—is to compress to about half the final pressure in the first cylinder, which is jacketed in the usual way, and the air is passed on to the second cylinder through an intermediate cooler (fig. 65). The final temperature is thus kept reasonably low. Of course, both the compressing cylinders are water-cooled, as well as the cooling effected in the inter-air cooler.

Most of the modern types of compressors are made to compress in stages, and the illustrations given are all of this class.

To put it briefly, it may be stated that to compress one pound of air to 60 pounds in one operation, the work expended would be about 47,300 foot pounds. If the same pressure is produced in two stages, with intermediate cooling, the work expended is only 42,600 foot pounds, or about 10 per cent saving. In both cases the compression is supposed to be

effected *without* cooling in the compressing cylinder. In higher pressures the saving effected is still more marked.

Bearing upon this subject, the Ingersoll-Sergeant Drill Company have furnished the following remarks, together with the table showing the comparative percentage losses in single, two, and four-stage compression :—

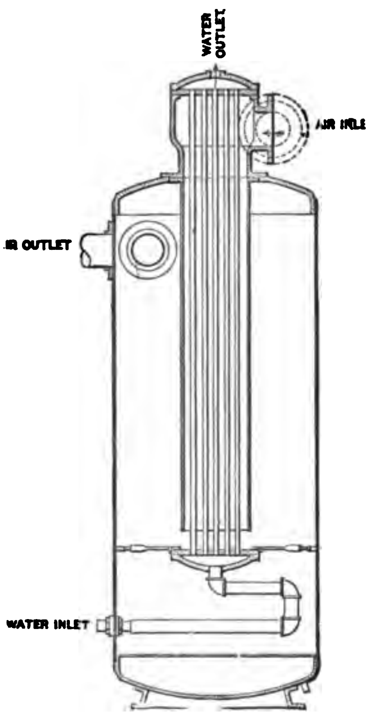


Fig. 65.
The Ingersoll-Sergeant Inter-cooler.

Builders of air compressors, and those who use compressed air, will agree that the problem of heating or cooling air is a difficult one. Hot air in the cylinder of an air compressor means a reduction in the efficiency of the machine. The trouble is that there is not sufficient time during the stroke to cool thoroughly by any available means. Water-jacketing is the generally accepted practice, but it does not by any means effect thorough cooling. The air in the cylinder is so large in volume that but a fraction of its surface is brought in contact with the jacketed parts. Air is a bad conductor of heat, and takes time to change its temperature. The piston, while pushing the air towards the head, rapidly drives it away from the jacketed surfaces, so that little or no cooling takes place. This is especially true of large cylinders, where the economy effected by water jackets is considerably less than in small cylinders. Engineers who are shown indicator cards from large air compressors, with pressure lines running away from the adiabatic, naturally regard them with suspicion, and look for leaks past the piston or through the valves. Such leaks will explain many isothermal cards, and until something better than a water jacket is devised it is well to seek economy in air compression through compounding.

The great advantage of compounding is in the fact that more time is taken to compress a certain volume of air, and that this

air, while being compressed, is brought in contact with a larger percentage of jacketed surfaces. The inter-cooler, which should always be used with compound machines, effects a larger saving by cooling, and thereby causing the air to shrink in volume between the stages. The trouble with inter-coolers is that manufacturers are too prone to build them of cheap construction, economising in machinery and in space and losing in thermic efficiency. A properly-designed inter-cooler should reduce the temperature of the air back to the original point—that is, to the temperature of the intake air. It can even do more than this, especially in winter, when the water used in the inter-cooler is of low temperature. A simple coil of pipe submerged in water is not an effective inter-cooler, because the air passes through the coil too rapidly to be cooled to the core, and such inter-coolers do not sufficiently split up the air to enable it to be cooled rapidly. This splitting up of air is an important point. A nest of tubes carrying water, and arranged so that the air is forced between and around the tubes, is an efficient form of inter-cooler. If the tubes are close enough together, and are kept cold, the air must split up into thin sheets while passing through. Such devices are naturally expensive, but first cost is a small expense when compared with the efficiency of the compressor, measured in the coal and water consumed.

Receiver inter-coolers are more efficient than those of the common type, because the air is given more time to pass through the cooling stages, and because of the freedom from wire-drawing which may take place in inter-coolers of small volumetric capacity.

After-coolers are in some installations as important as inter-coolers. An after-cooler serves to reduce the temperature of the air after the final compression. In doing this it serves as a drier, reducing the temperature of air to the dew point, thus abstracting moisture before the air is started on its journey. In cold weather, with air-pipes laid over the ground, an after-cooler may prevent accumulations of frost in the interior walls of the pipes; for where the hot compressed air is allowed to cool gradually, the walls of the pipe in cold weather act like a surface condenser, and moisture may be deposited on the inside, for the same reason that we have frost on the inner side of a window pane. Another advantage of the after-cooler is that it keeps the temperature of the line pipe uniform, otherwise the pipe will be hottest near

the compressor, gradually cooling down, and being thus subject to irregularities of expansion and contraction.

The following table will serve to illustrate the large saving that it is possible to effect by compounding. This table gives the percentage of work lost by the heat of compression, taking isothermal compression, or compression without heat, as a base.

Gauge Pressures.	One-Stage.		Two-Stage.		Four-Stage.	
	Per cent of work lost in terms of Isothermal Compression.	Per cent of work lost in terms of Adiabatic Compression.	Per cent of work lost in terms of Isothermal Compression.	Per cent of work lost in terms of Adiabatic Compression.	Per cent of work lost in terms of Isothermal Compression.	Per cent of work lost in terms of Adiabatic Compression.
60	30· p.c.	23·00 p.c.	13·38 p.c.	11·8 p.c.	4·65 p.c.	4·45 p.c.
80	34· ,,	25·26 ,,	15·12 ,,	13·12 ,,	5·04 ,,	4·80 ,,
100	38· ,,	27·58 ,,	17·10 ,,	14·62 ,,	8·00 ,,	7·41 ,,

In the above figures no account is taken of jacket cooling, it being a well-known fact among pneumatic engineers that water jackets, especially cylinder jackets, though useful and perhaps indispensable, are not efficient in cooling, especially so in large compressors. The volume of air is so great in proportion to the surface exposed, and the time of compression so short, that little or no cooling takes place. Jacketed heads are useful auxiliaries in cooling, but it has become an accepted theory among engineers that compounding or stage compression is more fertile as a means of economy than any other system that has yet been devised. The two and four-stage figures in this table are based on reduction to atmospheric temperature degrees Fahrenheit between stages. This is an important condition, and in order to effect it much depends on the inter-cooler. In this device we have a case of jacket cooling which in practice has been found to be efficient where engineers specify inter-coolers of the proper design. While cooling between stages we may split the air up into thin layers, and thus cool it efficiently in a short time, a condition not possible during compression. This splitting up process should be done thoroughly, and while it adds to the cost of the plant to provide efficient coolers, it pays in the end. A rule which might be observed to advantage among engineers is to specify that the manufacturers should supply a compressor with coolers provided with one square foot of tube-cooling surface for every ten cubic feet of free air furnished by the compressor when running at its normal speed.

Referring again to the table, we learn that when air is compressed to 100 pounds pressure per square inch in a single-stage

compressor without cooling, the heat loss may be 38 per cent. This condition, of course, does not exist in practice, except, perhaps, at exceedingly high speeds, as there will be some absorption of heat by the exposed parts of the machine. It is safe, however, to say that in large air compressors that compress in a single stage up to 100 pounds' gauge pressure, the heat loss is 30 per cent. This, as shown in the table, may be cut down more than one-half by compounding or compressing in two stages, and with four stages this loss is brought down to 8 per cent theoretically, and perhaps to 3 or 5 per cent in practice. As higher pressures are used the gain by compounding is greater.

As illustrating the progress made in air-compressing machinery some of the most successful types of high-class compressors are described in the following pages:—

THE INGERSOLL-SERGEANT COMPRESSOR.

A prominent place must be given to the compressor made by the Ingersoll-Sergeant Drill Company. This firm has long been famous for the manufacture of high-class mining and quarrying machinery, rock-drilling machines, and coal-cutting machines, and as these appliances depend so largely for motive power upon compressed air, it is not surprising that the Ingersoll-Sergeant Company has devoted its attention to air-compressing machinery.

The striking features of this machine are its high speed and noiseless working. Many of the air compressors with air-operated valves are terribly noisy—the Ingersoll compressor makes no more noise than a good steam engine. It is simple in construction, and its popularity at many modern British collieries is a sufficient indication of its reliability and efficiency.

The inlet for air is through what might be called a tail piston rod, except that instead of being a rod it is a hollow tube or pipe attached to the compressing piston.

The inlet valves are situated in the piston itself, and they depend for their operation upon a simple natural law, the law of inertia. The illustration (fig. 66) shows the valve **G**, which is simply a flanged ring. Slots are arranged to admit of its being built into the piston in such a way as to leave it free to

move through a short distance in the act of opening and closing. In the section, fig. 66, the piston is supposed to be moving to the left, and the valve on that side is closed, so that the air is being compressed finally to be forced through the delivery valve **H**. In the meantime, the inlet valve on the other side of the piston is open, and air is entering through the

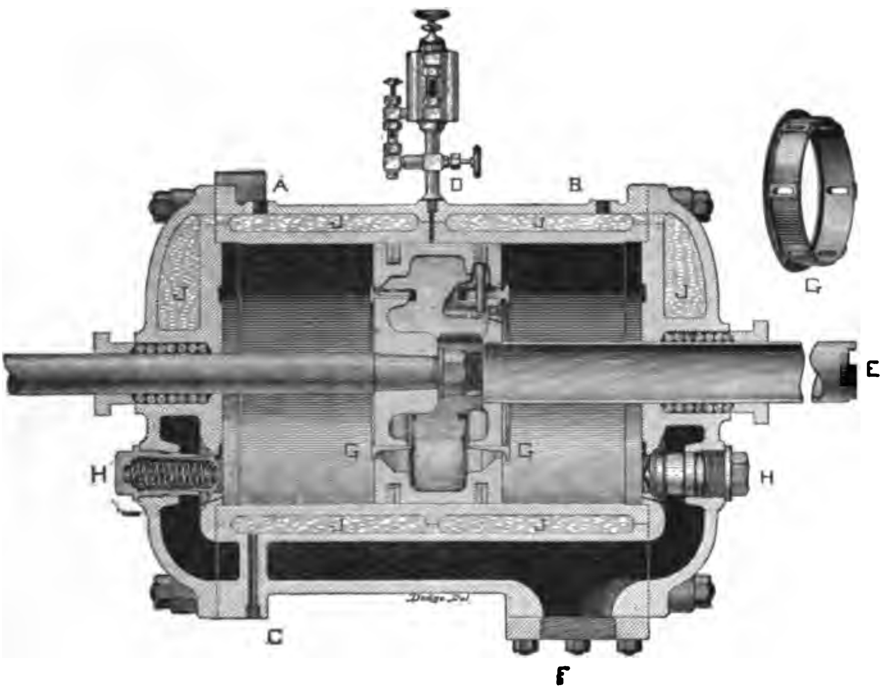


FIG. 66.

SECTION OF THE INGERSOLL-SERGEANT COMPRESSING CYLINDER.

hollow piston rod, and filling that side of the cylinder. When the end of the stroke is reached, and the direction of motion is reversed, the momentum of the open valve causes it to close, and the inertia of the closed valve causes it to open.

The compressing cylinder is entirely surrounded with a water jacket, the absence of inlet valves in the cylinder ends making it possible to jacket the ends as well as the sides.

The Ingersoll-Sergeant compressors are made to compress in one or more stages, with intermediate cooling, and it came somewhat as a surprise to the writer to learn that these compressors are made to compress up to 3000 pounds per square

inch, indicating a high standard of perfection. Of course, these high pressures are not intended for mining work, for which the pressures range from 60 to 110 pounds per square inch.

The Ingersoll-Sergeant Drill Company have furnished the following particulars, descriptive of the construction of their compressors, as well as a considerable amount of information relating to compressed air generally :—

DETAILS OF INGERSOLL-SERGEANT CORLISS AIR COMPRESSOR.

The Frames are of strong design, and are provided with a centre support with feet spread well apart, insuring great stiffness and strength.

The Cylinders are made of the best selected close-grained charcoal iron mixed with selected scrap, and are of proper strength and thickness for operating with 125 pounds' steam pressure after having been re-bored once. The material is such that the wearing surfaces become polished after a few days' use, after which, with reasonably dry steam, the wear amounts to so little that the piston remains tight for an indefinite length of time. The cylinders are neatly lagged, and the space between lagging and cylinder packed with non-conducting material to prevent condensation as much as possible. The steam passages are short and direct, reducing clearance to the least possible amount. The cylinder is supported upon two pedestals with extended base, with ample bearing surface on the foundation. The vacuum dashpots are secured firmly to the sides of these pedestals. Strong distance pieces are provided for connecting the air cylinders tandem to the steam cylinders.

The Shafts are of best wrought iron, of extra large diameter, and turned, key-seated, and nicely finished. The bearings are polished to reduce friction to the lowest point.

The Main Bearings.—The main pillow blocks are provided with removable shell boxes, with quarter boxes lined with genuine Babbit metal, hammered and scraped to fit the shaft. Approved means for taking up all lost motion is provided. The bearings are of ample length, and large oil boxes are provided with means for ready access to the shaft.

The Cranks are of the best selected charcoal iron, and of ample strength and proportion for the work to be done; they are of the disc pattern, and the weight of the connecting rod and crank pin

are counterbalanced on the opposite side, thus reducing end motion and vibration to the minimum. They are pressed on the shaft by hydraulic pressure, and securely keyed. The faces are turned and polished.

The Flywheels are extra heavy, of square rim pattern, the faces and edges being turned practically true. The arms are of ample length and well proportioned. The larger sizes are made in segments, accurately planed and fitted together with turned bolts in reamed holes. Rims of wheels are provided with starting-bar holes.

The Connecting Rods are of forged steel, with strap, gib, and key ends. The crosshead end is fitted with phosphor-bronze box, and the crank end with a composition box lined with the best Babbit metal, hammered, bored, and scraped to fit the pin.

The Crossheads are steel castings, provided with adjustable shoes for taking up all wear. The guides are V-shaped and scraped to a perfect surface. The shoes are lined with Babbitt metal, hammered and scraped to a perfect bearing in the slides. The crosshead pins are of forged steel, turned, polished, and fitted to the crosshead by a double taper. They are easily removed, and securely held in place by a nut or cap.

The Valve Gear is of the latest improved Corliss liberating type, fitted with vacuum dashpots. The connecting rods and pins are all of the best forged steel, and are fitted with phosphor-bronze bearings, adjustable for wear; provision for thorough lubrication is made, and the entire gear motion works smoothly and quietly. The catch blocks are of hardened steel.

The Valves are of the Corliss type, slotted at one end to receive the tee shaft heads of the valve stems, and are so constructed that any valve can be taken out without disturbing the valve stems or changing the adjustment of the valve gear.

It is only a few minutes' work to take all the valves out of the Corliss engine and put them back again, and this can be done by any engineer.

The Governor is of the fly-ball type, provided with an automatic safety stop, and operates in conjunction with an air-pressure regulator, which varies the cut-off and speed of the compressor in proportion to the volume of air used.

The Throttle Valves are furnished with flanges and large hand wheels, nicely turned and finished. A brass drain pipe leading to the exhaust is provided.

All usual oil cups and sight-feed lubricators for air and steam cylinders are provided of extra large size. A hand pump for steam cylinders and centrifugal oilers for cranks are also supplied, the lubrication being automatic throughout.

Indicator connections are furnished for each steam cylinder, with valve at each end, attached to water relief valve.

A full set of wrenches for adjusting all bolts and nuts is supplied with every compressor.

All necessary holding-down bolts, with anchor plates, together with foundation plans are furnished.

Fig. 67 represents a duplex Corliss compressor, with compound steam and compound air cylinders, recently installed by the Ingersoll-Sergeant Company at the colliery of the Cowpen Coal Company, at Blyth, Northumberland. The steam cylinders are 26 inches and 40 inches respectively, and the air cylinders 38¼ and 24¼ inches, first and second stage respectively. The stroke is 4 feet, and the piston speed 600 feet per minute. The capacity of the compressor at this speed is nearly 4800 cubic feet of free air per minute, which is compressed to 30 pounds in the low-pressure and about 80 in the high-pressure.

THE RIEDLER AIR COMPRESSOR.

The name of Professor Riedler, of Berlin, is associated with at least two highly-successful appliances which figure in the mechanical equipment of the colliery—the pump and the air compressor. Lord Kelvin, one of the greatest living British scientists, has been referred to as the man who invented a tap. Professor Riedler invented a valve, or rather a system of operating valves.

The fame of Lord Kelvin, who is responsible for some of the most valuable inventions and discoveries in the scientific and engineering world, is, perhaps, not altogether due to that tap; but there can be little doubt that Professor Riedler has become familiar to the mining world through his pump and air compressor valves.

Messrs. Fraser & Chalmers Limited, whose works are situated in the county of Kent, appear to be gifted with a considerable amount of what might be called engineering foresight. They have been quick to recognise the excellence, and carry out the application, of several comparatively new

mechanical details, among which figure the Riedler valves, applied to pumps and air compressors.

The writer would like to take this opportunity of expressing his gratitude to Messrs. Fraser & Chalmers for the immense

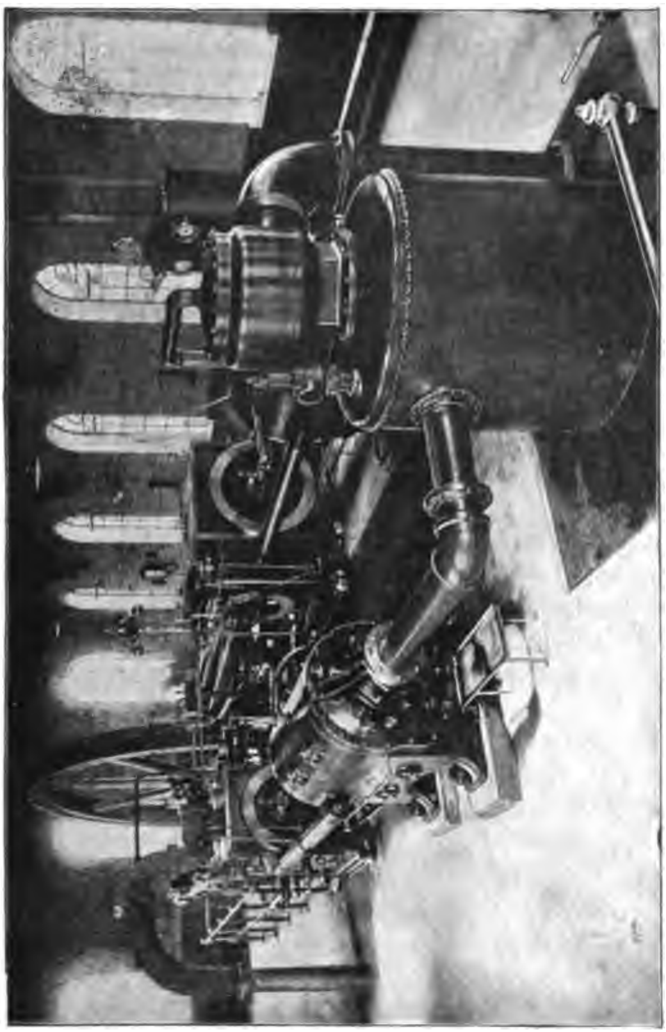


Fig. 67.
The Ingersoll-Sergeant Compressor at Cowpen Colliery, Blyth, Northumberland.

amount of valuable information which they have furnished for several of the sections of this work, as well as the illustrations, which it would have been difficult to procure from any other

source. A particularly pleasing and interesting feature in the case of several of the drawings supplied by Messrs. Fraser & Chalmers is the fact that they relate to the largest installations of their kind erected and working at British collieries.

The King-Riedler air compressor, illustrated in figs. 68 and 69 (*see sheet* 5, *between pages* 134 *and* 135), is a case in point; and when it is remarked that this compressor has a capacity of 8300 cubic feet of free air per minute, it will be recognised that we are dealing with what is perhaps one of the largest compressors at work in this country.

The air is compressed in two stages to a final pressure of 60 pounds, and provisions have been made to increase this in the future to 75 pounds. The normal speed of the compressor is 70 revolutions per minute, or 560 piston feet per minute, developing 1050 indicated horse power.

The engine is supplied with steam at 95 pounds, and is worked with a condenser.

From the illustrations figs. 68 and 69 (*see sheet* 5, *between pages* 134 *and* 135), which show the general arrangement, we see that the engine is of the vertical type. It is provided with an ingenious connecting rod arrangement, known as the King patent triangular connecting rod.

There are in all four steam and four air cylinders—two high-pressure and two low-pressure steam cylinders, and two high and two low-pressure air cylinders. In fact, there are two complete compound condensing engines with two-stage compressors, the whole coupled up to work as one machine, but so contrived that either side can quickly be disconnected and put out of action for any purpose. Between the two engines a 16-ton flywheel, about 16 feet in diameter, revolves, driven, as already remarked, by the patent triangular connecting rod.

The high-pressure steam cylinders are 23 inches in diameter, and the low-pressure cylinders 38; the air cylinders are 23 and 37 inches respectively, all 4-foot stroke. The steam cylinders are below, the air cylinders above; the high-pressure air above the high-pressure steam, and the low-pressure air above the low-pressure steam. The whole arrangement is clearly shown in the dimensioned drawings on sheet 5 (*between pages* 134 *and* 135), kindly placed at our disposal by Messrs. Fraser & Chalmers.

The valve gear on the engine is of the Corliss type, and the speed of the engine is accurately controlled by a pair of Whitmore's patent governors, by means of which the speed of the compressor is regulated according to the demand for air. If the demand is very little, the speed is automatically reduced to as low as 6½ or 7 revolutions per minute. On the other hand, if the demand for air is great the engine will speed up, but the governor will prevent an excessive speed—say in the event of a burst pipe,—and will not permit the engine to exceed the maximum by more than 5 per cent.

Most of the older types of air compressors are fitted with automatically-operated spring-loaded valves—that is, the valves open and close by the pressure of the air working against springs. This arrangement has many disadvantages which are entirely opposed to the economical working of the compressor. Take the inlet valves for example. If the spring tending to

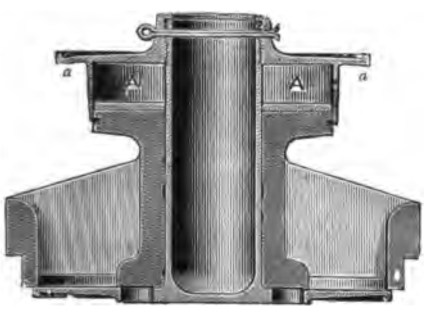


FIG. 70.
THE INLET VALVE.

FIG. 71.
THE OUTLET VALVE.

close the valve is weak enough to avoid the lowering of the suction pressure below that of the atmosphere (which means loss of efficiency), there is a good deal of chattering and a deafening row when the compressor is working. On the other hand, if the springs are strong enough to avoid this, there is the lowering of the suction pressure and a loss of efficiency.

In spring-controlled delivery valves similar defects are found. The compressor has to produce a pressure in excess of that in the receiver in order to compress the spring and open the valve. Here, again, we have a loss of efficiency; the engine has to do

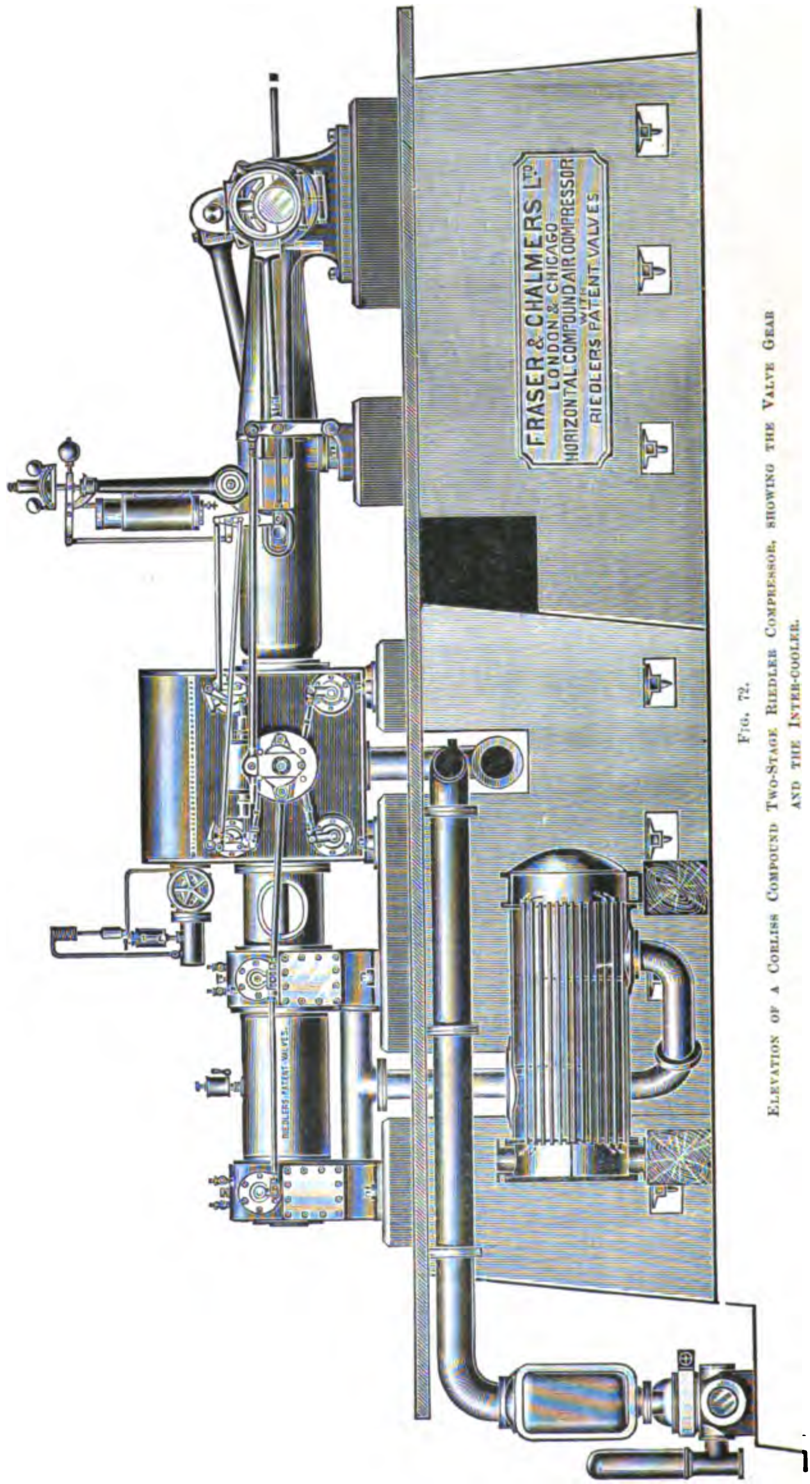


Fig. 72.

Elevation of a Corliss Compound Two-Stage Riedler Compressor, showing the Valve Gear and the Inter-cooler.

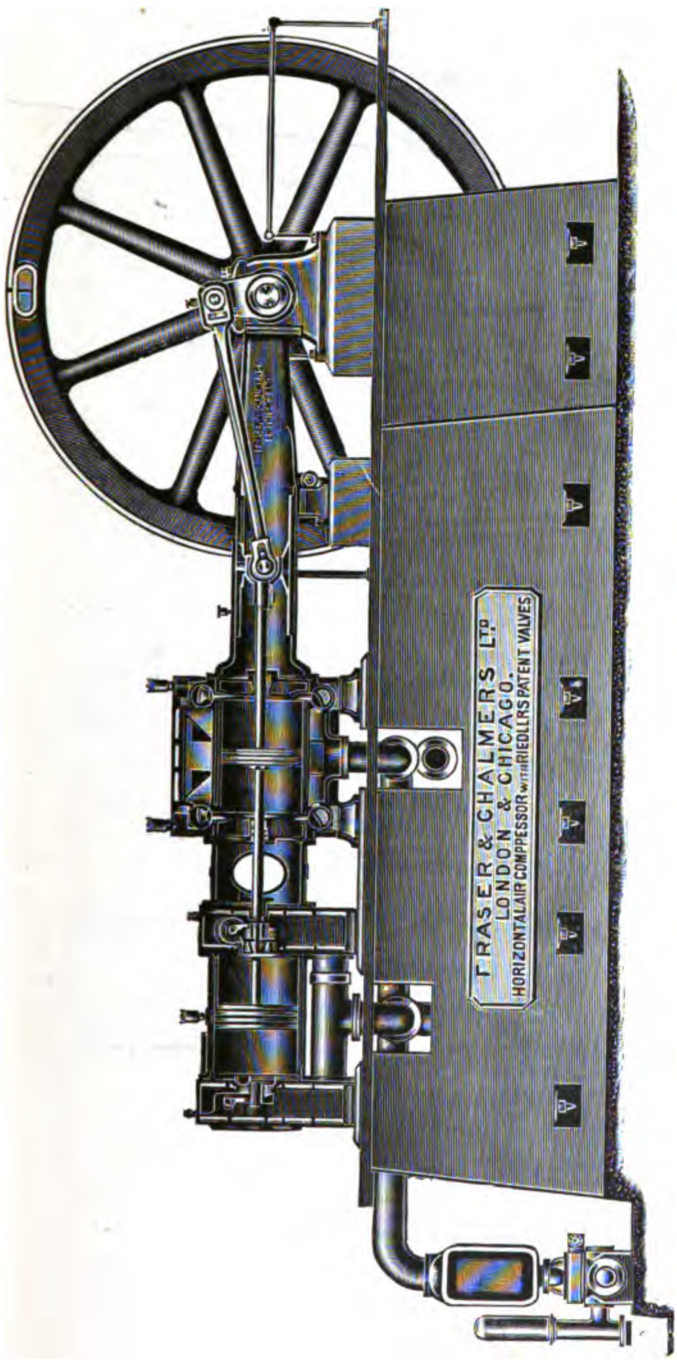


FIG. 78.

SECTIONAL ELEVATION OF THE RIEDLER COMPRESSOR.—THE AIR CYLINDER IS AT THE LEFT; ON THE GROUND BELOW THE ENGINE PILLAR ON THE LEFT A SURFACE CONDENSER AND AIR PUMP ARE SHOWN.

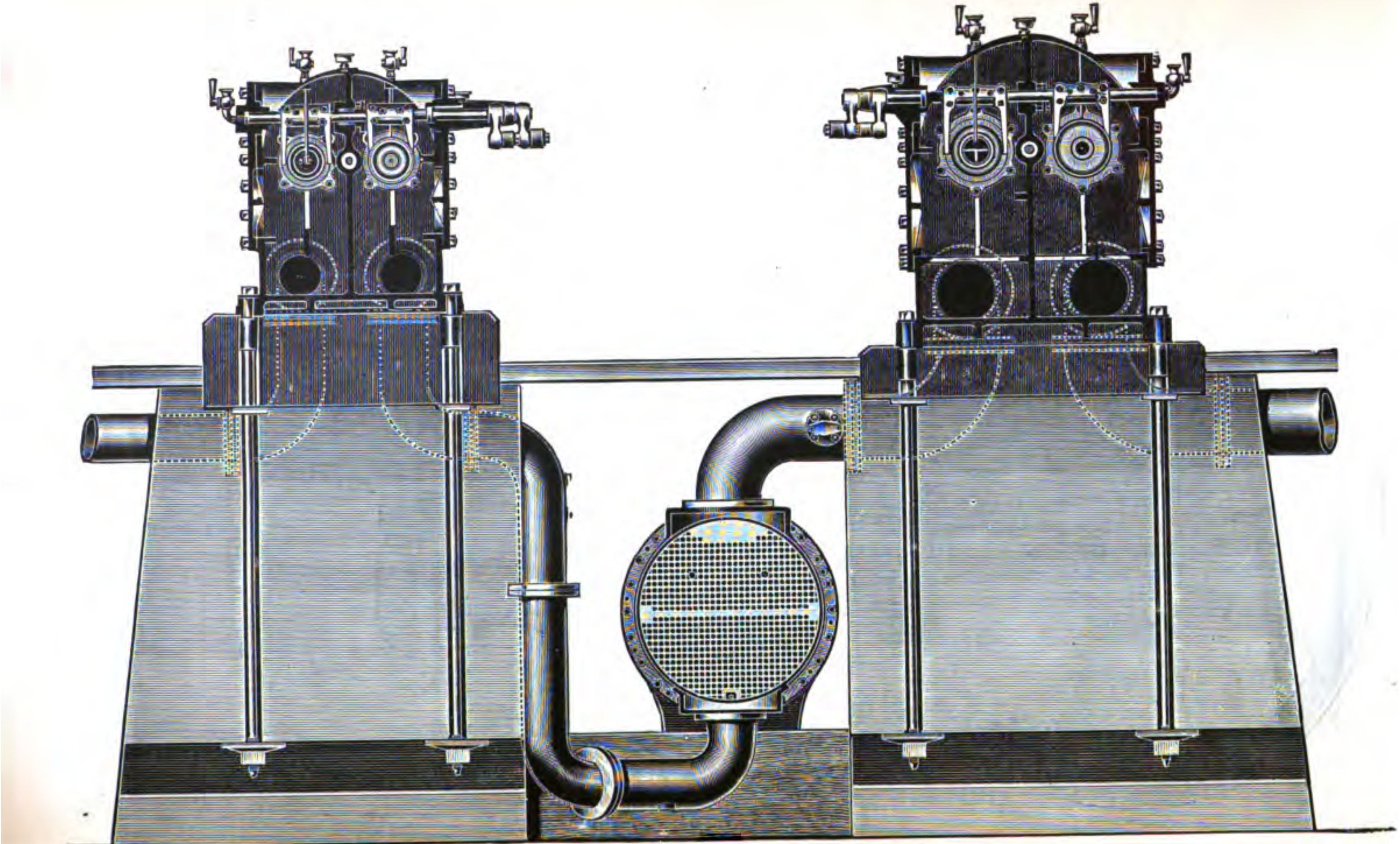


Fig. 74.

End Elevation of the Riedler Compressor, showing the Low-Pressure Air Cylinder on the right, the High-Pressure on the left. In each case the Inlet Valve is shown on the right and the Discharge or Delivery Valve on the left. The Inter-cooler is also shown between the two Engines.

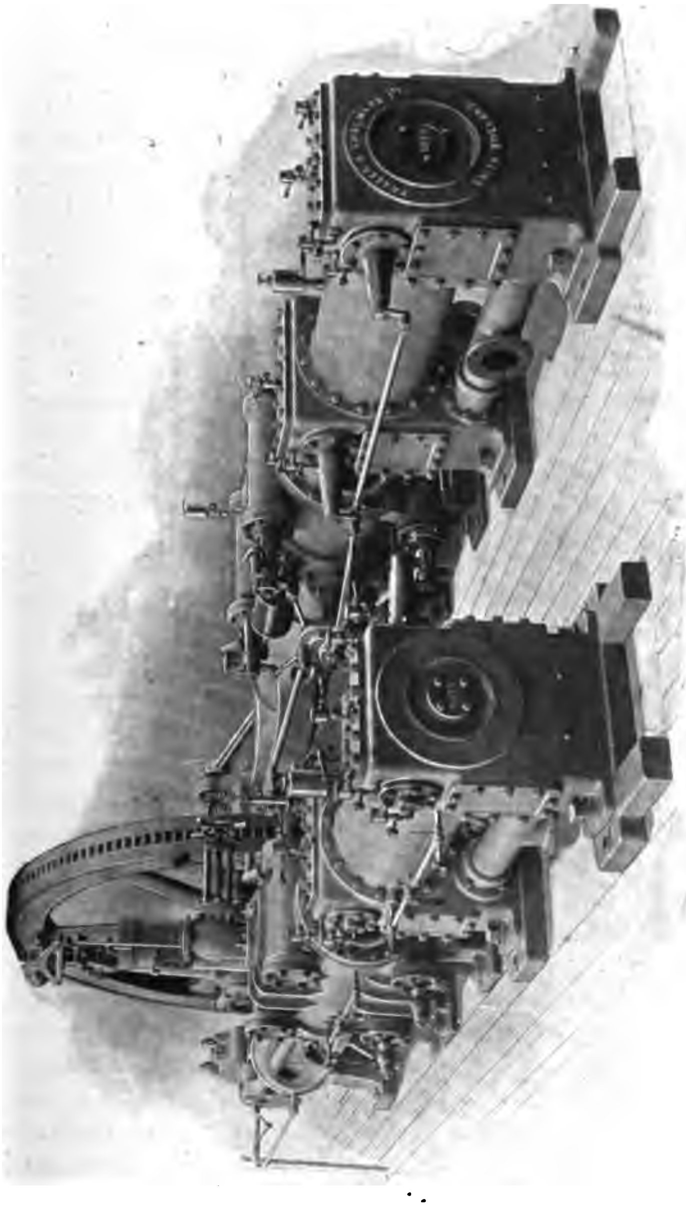


FIG. 75.

THE RIEDLER COMPRESSOR, CORLISS COMPOUND ENGINE, AND TWO-STAGE AIR CYLINDERS.

work in compressing the air to a higher pressure than actually necessary.

The Riedler valves and valve gear entirely obviate these difficulties. They are not mechanically operated entirely, which would be equally objectionable, but they are mechanically and positively closed. The inlet valves and the delivery valves are both free to open under the pressure of the air at the proper moment, but the closing is positively effected at the precise moment when they should close.

In the King-Riedler compressor described above, each air cylinder has one suction and one delivery valve at each end. The valves are very light, being made of forged steel turned from a solid block. The valve seats are of cast iron. The high-pressure valves have a lift of $1\frac{1}{4}$ inch and the low-pressure about $1\frac{1}{2}$ inch. (*See figs.* 70 *and* 71, *page* 135.)

The closing of the valves is effected by tappets, which draw the inlet valve back to its seat, or press the delivery valve down, as the case may be.

Figs. 72, 73, 74, and 75 (*see pages* 136, 137, 138, *and* 139) illustrate the Riedler horizontal compound two-stage compressor.

THE TEMPERATURE OF THE INLET AIR.

It is important that the air taken into the compressing cylinder shall be as cold as possible. The true significance of this is rarely recognised. The temperature of an engine room may be 80 degrees or 90 degrees, and if the air is taken into the compressor at this temperature there is a considerable loss of efficiency and capacity, as will be seen from the following:—Suppose we have 1000 cubic feet taken into the compressor at a temperature of 80 degrees, 90 degrees, and 100 degrees F. respectively, and discharged at 62 degrees F., a fair average of the temperature of the outer atmosphere, the volumes would be 966, 949, and 932. That is to say, at an engine room temperature of 90 degrees F., the air drawn into the compressor means a loss of over 50 cubic feet per 1000, or over 5 per cent as compared with air drawn into the compressor from the outer atmosphere at 62 degrees. Of course the saving in winter is even still greater by taking the air from outside.

The Ingersoll-Sergeant machine is easily arranged to take in air in this way; the inlet should be from the north side

side of the building, and the air should be filtered if there is any risk of dust.

THE LUBRICATION OF COMPRESSORS.

One so often reads of the absolute safety of compressed air as a means of power transmission, that it may come as a surprise to many of our readers to know that there are dangers—very serious dangers—which are to be guarded against in the working and using of compressed air. Indeed, as we have pointed out later in connection with electricity, the questions of safety and danger depend upon intelligence and the exercise of proper care and due precautions rather than upon any inherent characteristics of the particular form of energy concerned. Energy in any form can work destructively; and compressed air, as a means of transmitting energy, is not free from elements of danger, or, rather, from features which call for the reasonable exercise of care and common-sense.

Compressing cylinders have burst in consequence of internal ignition and explosion. Receivers have exploded from the same cause, and in some of these cases such explosions have been attended with loss of life. Men working in an atmosphere into which the exhaust from an air-driven engine is discharged have been rendered unconscious by carbon-monoxide poisoning. Both these dangers depend upon the lubrication of the compressing cylinder and the quality of the oil used. For example, air compressed to 60 pounds above the atmosphere without cooling has a temperature of about 380 degrees F., and as mineral oils have a flash-point as low as 300 degrees F., the result is obvious; and when we remember that the explosive force is increased by compression, we see what may happen if the lubricant contains any mineral oil. The latter is vaporised, and forms a highly-explosive mixture with the air, and if the temperature is high enough ignition of this may take place. In any case, the use of unsuitable oil tends to the production of carbon-monoxide gas, the high temperature bringing about the partial combustion or decomposition of the vaporised hydrocarbons. Only high flash-point oils, specially prepared for the purpose, should therefore be permitted for air cylinders.

THE NEW WORTHINGTON AIR COMPRESSOR.

The Worthington compressor, made by the Worthington

Pump Company Limited, whose pumping appliances have a high reputation all over the world, furnishes another example of a compressor with mechanically-operated valves. Perhaps it would be more correct to say that the Worthington compressor combines both the mechanically-controlled and the automatic poppet valves. An inspection of the sectional view of the compressing cylinder, fig. 76, will make the arrangement

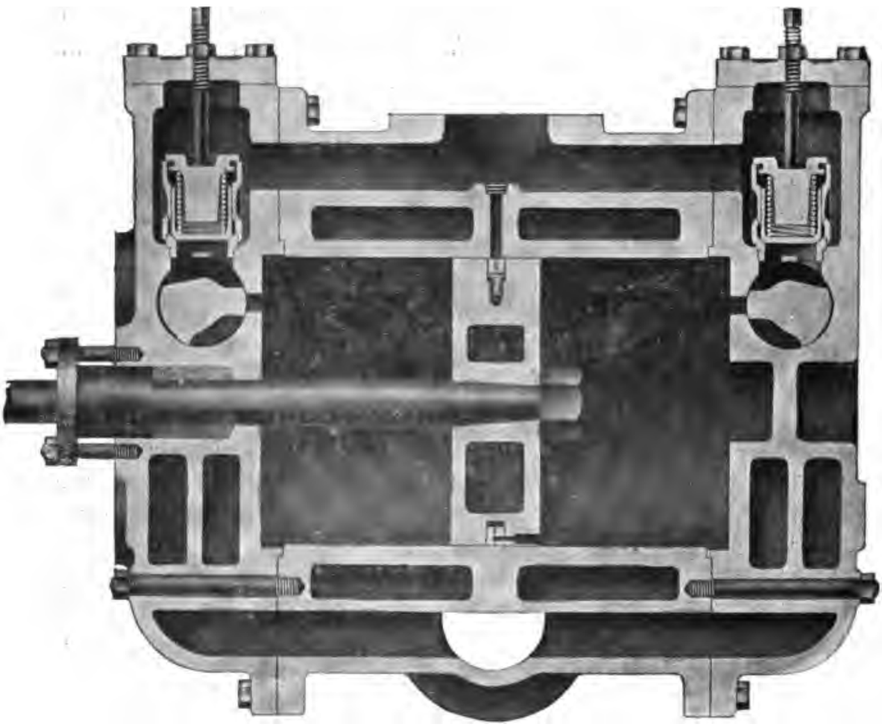


FIG. 76.
SECTION OF THE WORTHINGTON COMPRESSOR.

clear. Both the inlet and discharge are controlled by the Corliss valve, one at each end of the cylinder. During the suction stroke the Corliss valve puts the cylinder in communication with the atmosphere, and cuts off the communication at the moment the stroke is completed. During the compression stroke the Corliss valve opens for the passage of the compressed air through the delivery port and through the spring-loaded poppet valve. The Corliss valve remains open until the end of the stroke, but closes immediately the stroke is completed. The

poppet valve has now the whole period of the return stroke in which to close, and as the air is practically at the same pressure on both sides, the valve closes gently and noiselessly. It will be evident, of course, that the closing of the Corliss valve prevents the re-expansion of the air in the delivery port on the return stroke, thus reducing clearance losses.

The following detailed particulars, furnished by the Worthington Company, fully describe the construction of their latest type of compressor :—

DETAILS OF CONSTRUCTION.

General Arrangements.—The location of the air cylinders just behind the steam cylinders relieves the engine parts of all work, beyond that involved in equalising the variation in steam-cylinder pressure to the requirements of the air-piston load. More than this, it leaves completely open to observation and access all those working parts which most frequently require the engineer's attention; these parts being the main bearings, the connecting rod, and the crosshead bearings. The weight of the reciprocating parts is also kept within safe limits by this arrangement, no heavy yokes or stretcher rods being required. Perfect and permanent alignment is insured by joining the cylinders to the frames and the housings to the cylinders by close-fitting counterbores, which make the alignment automatic and unchangeable, the cylinders and frames being bored and faced at the same setting. Full provision is made in the design, moreover, for easy access to all cylinder-head joints, permitting their renewal without disturbing the cylinders.

Frame.—The frame is of a modified and heavy rolling-mill type, designed to afford a long and massive bearing on the foundations in order to sustain in the most effective manner the great weight of the flywheel. The weight of the frame is sufficient to properly absorb pulsations caused by the alternating push and pull of the varying air loads and by the inertia of the reciprocating parts, which, as engineers are aware, even the most perfect balancing cannot completely neutralise. The metal is so distributed as to bring the strains in a direct line with the heavily ribbed and bored guide barrel. The entire frame is cast in a single piece.

Main Bearings.—The main bearings are of the quarter-box type, the adjustment for side wear thus being completely inde-

pendent of the adjustment for vertical wear. The bearings are provided with cast-iron shells lined with genuine Babbitt metal, hammered, bored, and scraped to a fit; the design being such as to permit the removal of the side shells without disturbing the shaft. Wedge-and-bolt adjustment is provided for the wear of the side shells. The heavy bearing cap is so interlocked with the frame as to provide a strong tie.

SHAFT.—The shaft is of forged iron or steel, free from flaws or imperfections.

CRANKS.—The cranks are of the disc type, balanced and cast of the best grade of charcoal iron. They are so proportioned as to reduce to a minimum the overhang beyond the main bearing. The crank pins are forged iron, pressed into the cranks, and are set at an angle of 90 degrees with each other on duplex and cross-compound machines.

CROSSHEAD.—The crosshead is of the box pattern, fitted with adjustable babbitted slippers on both top and bottom, these slippers working in bored cast-iron slides, bored concentric with the cylinder, and of unusually large bearing surface.

CONNECTING ROD.—The connecting rods are of forged steel with rigid rectangular section. The crosshead ends are fitted with bronze boxes, and the crank pin ends with babbitted boxes, both being provided with wedge-and-screw adjustment.

FLYWHEEL.—The rim is square in section and is turned true on the face and sides. The wheel is keyed to the shaft, and barring holes are cast in the face.

LUBRICATORS AND OIL GUARDS.—A convenient system of automatic lubrication is provided, together with conveniently arranged drains for collecting the oil after use.

BED PLATES.—A heavily ribbed bed plate of box section extends from the steam cylinder foot on each side under the corresponding air cylinder foot, thus giving each side of the machine two long bearings on the foundation, one under the frame end and one under the steam and air end.

STEAM CYLINDERS.—The steam cylinders are cast of specially selected, hard, close-grained iron, and are bored true and smooth, having walls of sufficient thickness to permit re-boring. The cylinders are covered by a suitable non-conducting material, and are neatly lagged in Russia iron.

STEAM VALVE GEAR.—In the smaller machines a steam valve gear of the well-known Meyer type is used, the distinguishing

feature of which lies in the employment of a pair of auxiliary valves working on the back of the main valve and actuated by an independent eccentric. These cut off the supply of steam to the cylinder at a point in the stroke determined by their relative positions.

The relative motion is controlled by a right and left thread on a swivel with a square stem, the square portion moving within the spindle of the stationary hand wheel shown in the illustration. The movement of the wheel shortens or lengthens the cut-off as may be desired. An index plate is mounted on the wheel bracket, indicating the point at which cut-off is taking place.

In designing the steam end of the medium size and large machines, a valve gear is provided in which the operating economies of the Corliss type are retained, while its disadvantages, from a compressor point of view, are eliminated. The well-known advantages of Corliss gear consist in the use of separate steam and exhaust valves, resulting in reduced initial condensation, permitting partial balancing of both the steam and exhaust valves, and allowing short, straight ports, with correspondingly reduced clearance. The Corliss type, on the other hand, is objectionable for relatively high speeds because of the restriction in speed imposed by the releasing gear and because of its complication and expense.

The exhaust valves are of the Corliss semi-rotary type, placed at the bottom of the cylinders. Steam distribution is effected by a slide valve working on straight, short ports at each end. The action is absolutely positive, and the cut-off is adjustable between one-fifth and three-fourths stroke, giving a wider range than is obtainable with the Corliss gear, and allowing, therefore, a considerably greater margin of power. In addition to these features, the gear retains the principal advantages of the Corliss motion—namely, short port volume and correspondingly low clearance, combined with separate passages for admission and exhaust, and greatly reduced friction in operation.

Steam and Air Pistons and Piston Rods.—The pistons are fitted with Harris-Babbitt self-adjusting rings, which are made in segments in order that they may accommodate themselves closely to slight changes of the cylinder bore due to wear. The joints are broken, and the segments are held out by light springs of German silver wire. The piston is simple, durable, and tight, and runs with less friction than any other type made.

The piston rods are of the best machinery steel, are turned smooth and highly polished, and are screwed into the crossheads with coarse threads, and are secured by lock nuts. Taper holes are bored and reamed in the steam pistons, into which the rods are fitted and held by nuts.

AIR CYLINDERS.—The air cylinders are cast of special, hard, close-grained iron, are bored true and smooth, and are sufficiently heavy to permit re-boring. Both cylinders and heads are effectively water-jacketed; the cylinders completely, and the heads throughout that portion below the valves. The water jacket is interposed between the cylinder and the suction passage through the head, thus bringing the inlet air to the valve in the coolest possible condition.

AIR VALVE GEAR.—The air valve gear has always been the greatest obstacle to even moderate speeds in compressors as compared with ordinary engine speeds. The ideal gear is, of course, one which is positively moved from an eccentric on the engine shaft, or from some reciprocating part of the engine. The difficulty, however, is that there is a lack of elasticity, and it is not applicable unless a fairly constant discharge pressure can be counted upon, as in the case of the low-pressure cylinders of two-stage machines.

In contrast to the objections to the best previous types of mechanically-moved valves, as noted above, are the still greater objections to poppet valve machines for the highest class of service. The poppet valve, while perfectly automatic and elastic in its operation, is open to the objections of comparatively rapid wear and noisy action. Both these objections are due to the impact of the valves on closing at the reversal of the stroke, and while not serious on machines running at the ordinary compressor speeds, rapidly increase in importance with increase in the number of revolutions per minute. As a means of partially overcoming these bad features, compressors are very frequently built with mechanically-moved inlet valves and poppet discharge valves. This construction, while most satisfactory at moderate speeds, and while eliminating the wear and noise on the suction valves, fails, however, to eliminate the noise and wear caused by the violent closing of the poppet discharge valves. In fact, this latter objection is rather intensified, since, as ordinarily set, the mechanically-moved suction valves open before the air in the clearance spaces has expanded down to atmospheric pressure, thus robbing the discharge valve of some of its cushion in closing.

The Worthington valve gear, as an examination of fig. 76 (*see page* 142) will show, mechanically and positively controls the three constant points in the compression cycle—namely, the opening of the suction, the closing of the suction, and the closing of the discharge. The opening of the discharge, which is the variable event in the cycle, is effected by means of poppet valves. At the end of the stroke, however, the discharge is mechanically closed by means of the Corliss semi-rotary valves, thus retaining under the poppet discharge valves a cushion of air under receiver pressure. These poppet valves are therefore given the entire return stroke in which to seat themselves, and all tendency to violent and noisy impact in closing is removed. In addition to this an extremely low clearance is assured, combined with very large port areas and unusual accessibility to all working parts. It will be noted that this valve gear has every feature essential to quiet and efficient operation at high speeds.

INTER-COOLER.—Two-stage machines are fitted with an improved tubular cooler between the high and low-pressure air cylinders. This cooler is placed above the cylinders in a position where it may easily be inspected. It is identical in construction with the best type of surface condenser. The cooling surface consists of a nest of small brass tubes, easily accessible for cleaning or renewal, through which water circulates, and in the arrangement of which full provision is made for expansion and contraction. These tubes thoroughly break up the stream of air entering the cooler, while their thin walls insure rapid conduction. They do not rust nor foul, and retain their effectiveness indefinitely. The large receiver volume formed by the connecting pipes and inter-cooler body results in a nearly uniform discharge pressure in the low-pressure cylinder—a point of especial importance with mechanically-moved valves. The air, being outside of the tubes, encounters practically no frictional resistance, and its slow passage affords ample time for thorough cooling. A pocket, with a gauge glass attached, is so placed that any precipitated moisture which might otherwise enter the high-pressure cylinder is easily drawn off.

THE SENTINEL AIR COMPRESSOR.

The compressor illustrated in figs. 77 and 78 (*see pages* 148 *and* 149) is the production of Messrs. Alley & MacLellan Limited, of the Sentinel Works, Glasgow.

The names of most of the large modern engineering firms seem to be associated with some particular appliance or class of machinery, and the name of Alley & MacLellan has always been associated in our mind with an excellent type of high-speed engine, to which reference has been made elsewhere.

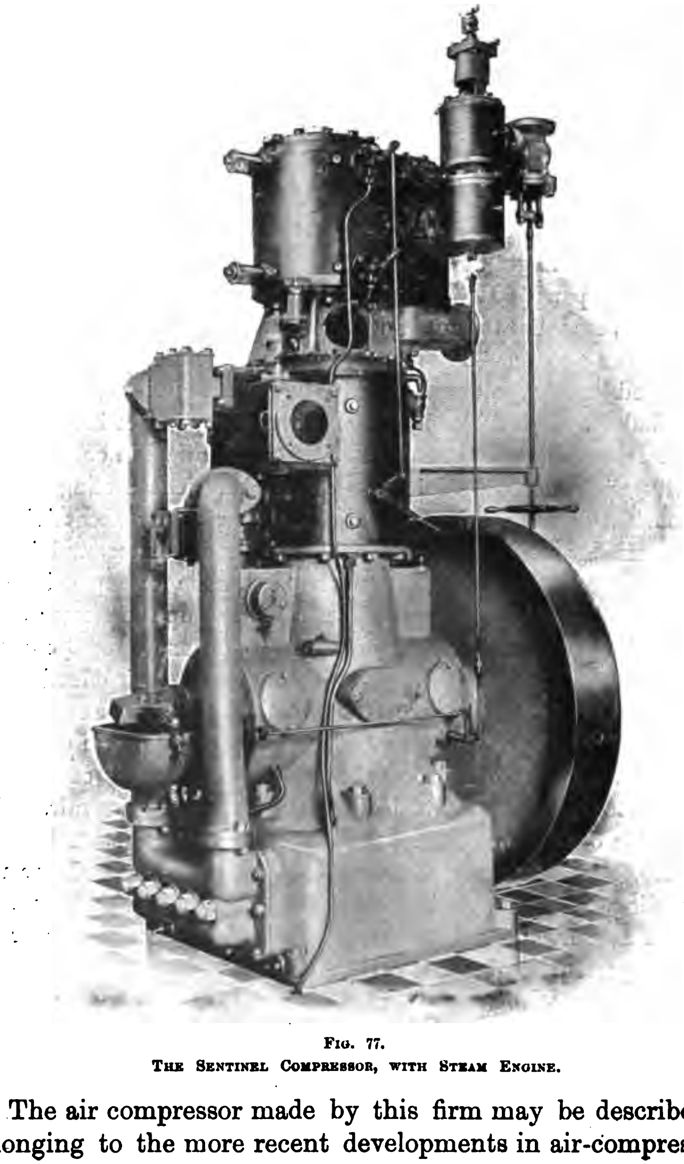


FIG. 77.
THE SENTINEL COMPRESSOR, WITH STEAM ENGINE.

The air compressor made by this firm may be described as belonging to the more recent developments in air-compressing

machinery, and it presents features quite peculiar to itself, deserving our careful consideration.

It is essentially a vertical two-stage compressor, but the two stages of compression are effected in what is virtually one

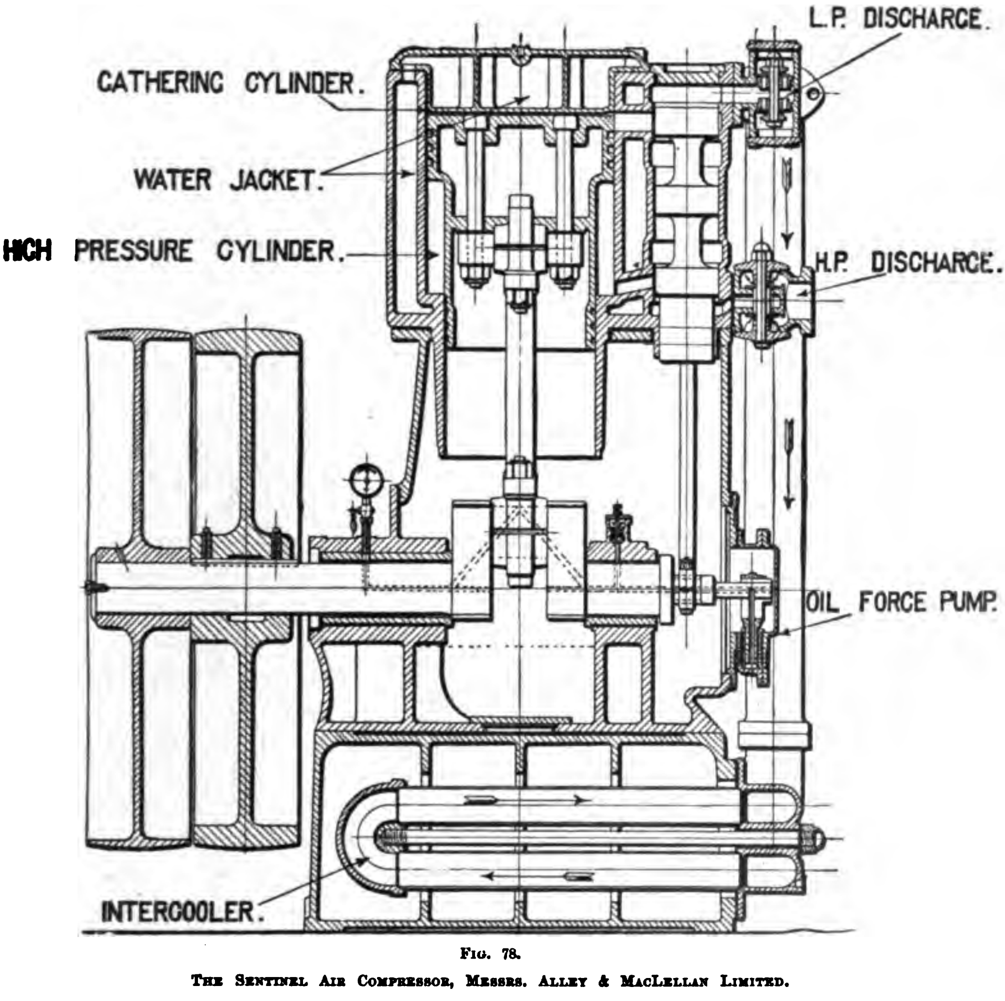


Fig. 78.

The Sentinel Air Compressor, Messrs. Alley & MacLellan Limited.

cylinder. Reference to fig. 78 will help to make our explanation clear, from an inspection of which it will be seen that the piston is an elongated trunk piston, the upper part being of larger diameter than the lower, with a set of Ramsbottom piston rings at the top and another at the bottom. This trunk piston

is connected directly with the crank by means of the connecting rod, as in the ordinary gas engine, the length of the piston obviating the necessity for a crosshead and slide bars. The cylinder in which the piston works is also of differential diameter, corresponding with the two diameters of the piston, so that between the lower side of the larger diameter of the piston and the top of the smaller diameter of the cylinder there is an annular space, which serves the purpose of the second-stage compressor.

The first stage of compression is effected in what is described in the illustration as the gathering cylinder, that is the top of the cylinder above the large diameter of the piston. On the downstroke air is drawn into this space, compressed by the next succeeding upstroke, and discharged through the inter-cooler into the annular space already described. During the downstroke the air in this space is compressed to the final pressure. At this point, the makers claim, the cooling is very effective, and their explanation appears to be reasonable. They point out that instead of a solid *cylinder* of air—only a comparatively small surface of which comes in contact with the water-cooled walls of the cylinder—there is merely a cylindrical shell of air, which presents a much larger surface, in proportion to its volume, for contact with the water-cooled cylinder walls. It will be observed that the compressor is single-acting each way; that is, the first stage compressed is effected during the upstroke, and the second stage during the downstroke.

The whole arrangement is totally enclosed, and the lubrication is specially provided for by means of the small oil force-pump, which delivers oil, under pressure, to all the bearings.

The sectional illustration (fig. 78, *see page* 149) represents a single-cylinder compressor, intended to be driven by a belt. They are also arranged with a steam cylinder, tandem fashion (*see fig.* 77, *page* 148), and for driving by electric motor.

The valve gear is illustrated in fig. 79. The arrangement is of the combined mechanical and automatic type, and in working the compressor is silent and entirely free from that clattering and banging common to the older types of compressors with automatic disc or hinged valves. The air is admitted, in the first instance, through the air screen or filter shown on the left side in fig. 79, and through the equilibrium valve, to which

we shall again refer presently. The actual inlet to the compressing cylinder is controlled by the piston valve, operated by the usual eccentric (*see fig.* 78, *page* 149), and this piston valve also controls the discharge. Still referring to fig. 79, the piston valve is shown in section, with its several ports, and the end of

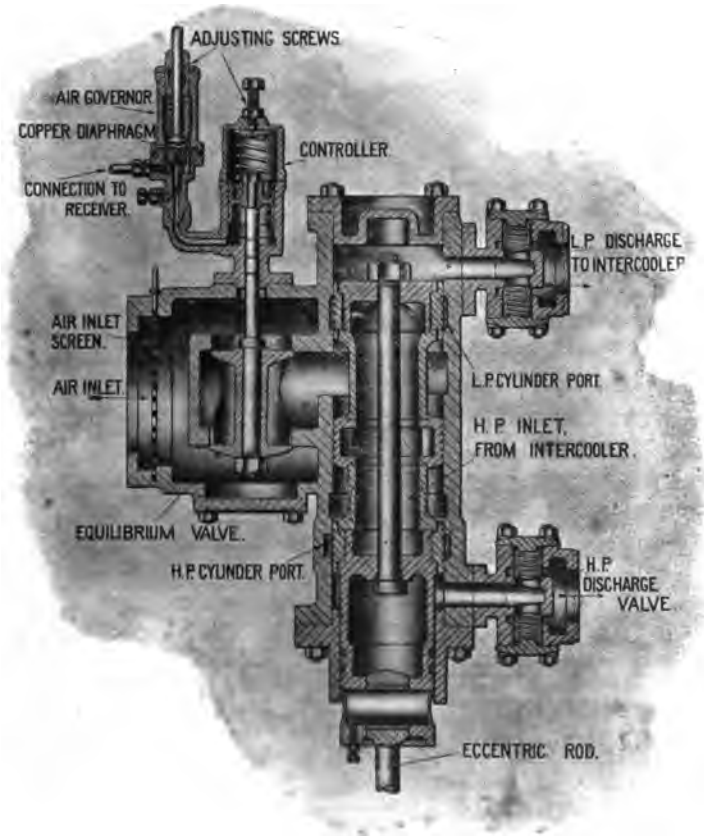


FIG. 79.
THE VALVE GEAR OF THE SENTINEL COMPRESSOR.

the eccentric rod shown at the bottom. At the proper moment the piston valve opens the inlet ports and admits air to the cylinder, and as promptly closes admission at the end of the suction or in-drawing stroke. During the discharge of compressed air the piston valve opens the ports for the passage of the compressed air, which must also pass through lightly-

loaded spring poppet valves before passing to the high-pressure cylinder or to the receiver, as the case may be. To make the action clear, suppose the air, compressed to the final pressure, is being discharged into the receiver. It passes first through the port, which is opened at the right moment by the piston valve, and then through the high-pressure discharge valve. (*See fig.* 79, *page* 151.) At the precise moment of reaching the end of the stroke, the piston valve closes the communication behind the compressed air, cutting off communication with the compressing cylinder and leaving the poppet valve almost in a state of equilibrium, with air at the same pressure on both sides. The poppet valves thus take their own time to close, and do so gently and without shock or noise.

To return now to the inlet equilibrium valve. It will be seen in the illustration, fig. 79 (*see page* 151), that this is operated by a controller attached to the top end of its elongated spindle. The controller takes the form of a small spring-loaded piston working in a small cylinder, the underside of which communicates through the air governor arrangement with the compressed air receiver. The object of this arrangement is to control the action of the compressor and close the inlet equilibrium valve in the event of the normal working pressure being exceeded when air is being delivered into the receiver faster than it is being used.

Suppose, for example, the compressor is intended to work at 80 pounds per square inch, and the pressure in the receiver tends to exceed this, say rising to 82 pounds; immediately the air operates through the connecting pipe upon the air governor, which can perhaps best be described as a small spring-loaded relief or safety valve; this valve opens and admits air to the underside of the spring-loaded piston in the controller, which, as a consequence, is raised and the equilibrium valve below is closed. The compressor no longer takes in air and the work of compression ceases, the machine runs light, and, if it be of the steam-engine type, the speed of the latter is reduced by the operation of the engine governor until the pressure in the receiver again falls below the normal, when the reduced pressure allows the inlet equilibrium valve to open and the work of compressing is resumed. If the compressor is electrically driven the speed will remain constant, but the current consumption will, of course,

be reduced to correspond with the energy merely necessary to keep the machine in motion without doing any work of compression.

The system of forced lubrication tends to a high mechanical efficiency and a freedom from excessive wear and tear. The makers claim that the mechanical efficiency is as high as 93 per cent; that is to say, if 100 horse power is required to work the compressor on full load, not more than seven horse power is absorbed in overcoming the friction of the machine itself.

The illustration used for the purpose of describing the action of this compressor shows a single-cylinder machine. The arrangement the makers recommend, however, is the three-cylinder three-crank arrangement—that is to say, three of the cylinders illustrated, or three compressors side by side, worked together by means of a three-throw crank. This not only gives a more uniform torque, but, as the makers point out, the cooling surface for a given volume of air in three small cylinders is much greater than the cooling surface in one cylinder of the same capacity, and therefore the cooling is more effective.

We are familiar with the excellence of Messrs. Alley & MacLellan's engineering work generally, we know that this compressor is in high repute in several very large and important engineering works where air-compressing plant is in demand, and we place these particulars before our readers with the full confidence that they refer to a compressor of the highest possible class.

THE REAVELL AIR COMPRESSOR.

Although to a great extent compressed air and electricity are looked upon as rivals in the field, our belief is that in many cases the two might very profitably join forces, and a most useful combination would result. Messrs. Reavell & Co. Limited, of the Ranelagh Works, Ipswich, have anticipated such a combination of forces, and have perfected a very compact electrically-driven air compressor for use in mines.

In conformity with modern practice these are made either as single or two-stage compressors, and their compactness and very portable character will be gathered from a glance at fig. 80 (*see page* 154), which shows a portable Reavell compressor complete, with motor, air filter, etc.

Referring to fig. 81, it will be seen that the compressor consists of four cylinders arranged in a circular-shaped casing. The cylinders are arranged radially at opposite ends of two diameters, intersecting at right-angles with each other. Each cylinder is fitted with a trunk piston, all four of which are driven by one crank. Each cylinder is a single-acting compressor, and the combined effect of the four, coupled to one crank, is to produce a very uniform load. The circular casing is divided, by means of the three black concentric circles shown in the section, into three parts. Within the inner black circle, in which

Fig. 83.

The Reavell Portable Air Compressor, with Electric Motor.

the crank and connecting rods work, we have the suction chamber. The air finds its way into each cylinder during the suction stroke, partly through the hollow gudgeon of the connecting rod, in which holes or ports are arranged with corresponding ports in the piston, and partly through the ports in the walls of the cylinders, which are put into communication with the suction chamber when the piston reaches the outer end of the cylinder.

The annular space between the inner circle and the second circle forms the water jacket, and the narrow annular space

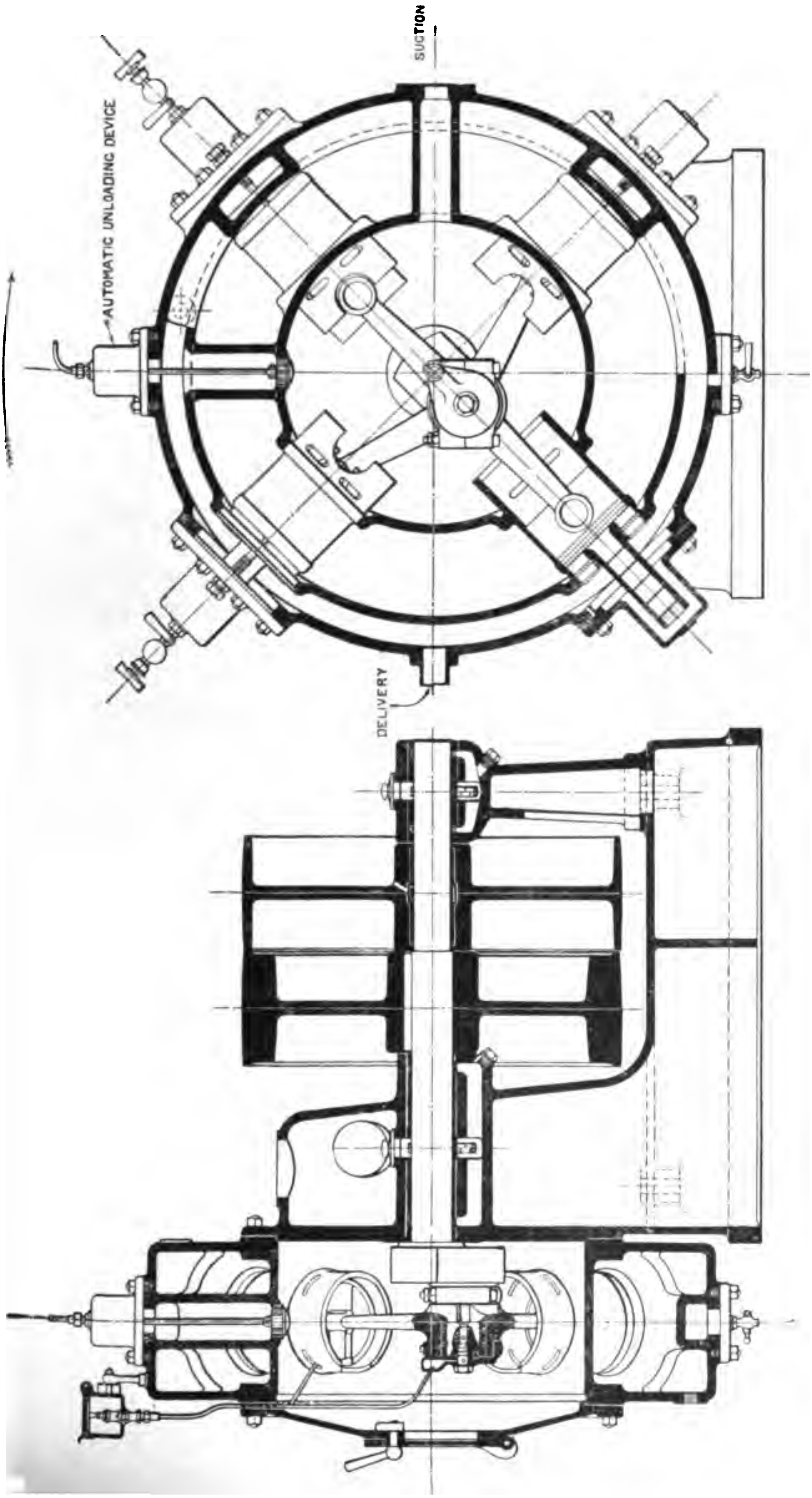


Fig. 81.—The Reavell Compressor.

between the second circle and the outer circle forms the delivery and the receiver. The delivery valves are placed in the end of each cylinder.

The sectional illustration shows a single-stage belt-driven type; a two-stage type machine would simply consist of two sets of cylinders, one set smaller than the other, for the second-stage compression. The arrangement for electrical driving is a compact arrangement in which the motor is direct-coupled to the compressor. The motor occupies a position in the middle; one circular casing with the low-pressure cylinders is fixed at one end, the other with the high-pressure cylinders at the other, with one shaft common to all. Only two bearings are necessary for this shaft, one on each side of the motor. An inter-cooler is provided, through which the air passes from the first to the second stage.

The automatic unloading device, shown at the top of the sectional drawing, is a contrivance which has the effect of putting the delivery chamber into communication with the suction chamber in the event of the pressure in the pipes or receiver exceeding the predetermined limit. The machine then runs light, consuming only sufficient current to overcome its own friction until the pressure falls, when the work of compression is immediately resumed.

It will be seen that a compressor of this type is an admirable arrangement for working at or near the coal face or other portion of the mine, for driving rock drills or coal-cutting machines requiring compressed air for their manipulation. Full advantage may thus be taken of the higher efficiency of electricity for long-distance transmission, whilst the compressor, being close to its work, the losses due to compressed-air transmission are reduced to a minimum.

THE NORWALK COMPOUND AIR COMPRESSOR.

Fig. 82 represents the Norwalk compound compressor, made by the Norwalk Ironworks Company, Connecticut, and for which Messrs. John Davis & Son, of Derby, are the British agents. The makers strongly advocate the desirability of taking the air into a compressor as cool and as clean as possible, and they recommend wooden air conduits for the conveyance of air to the compressing cylinders.

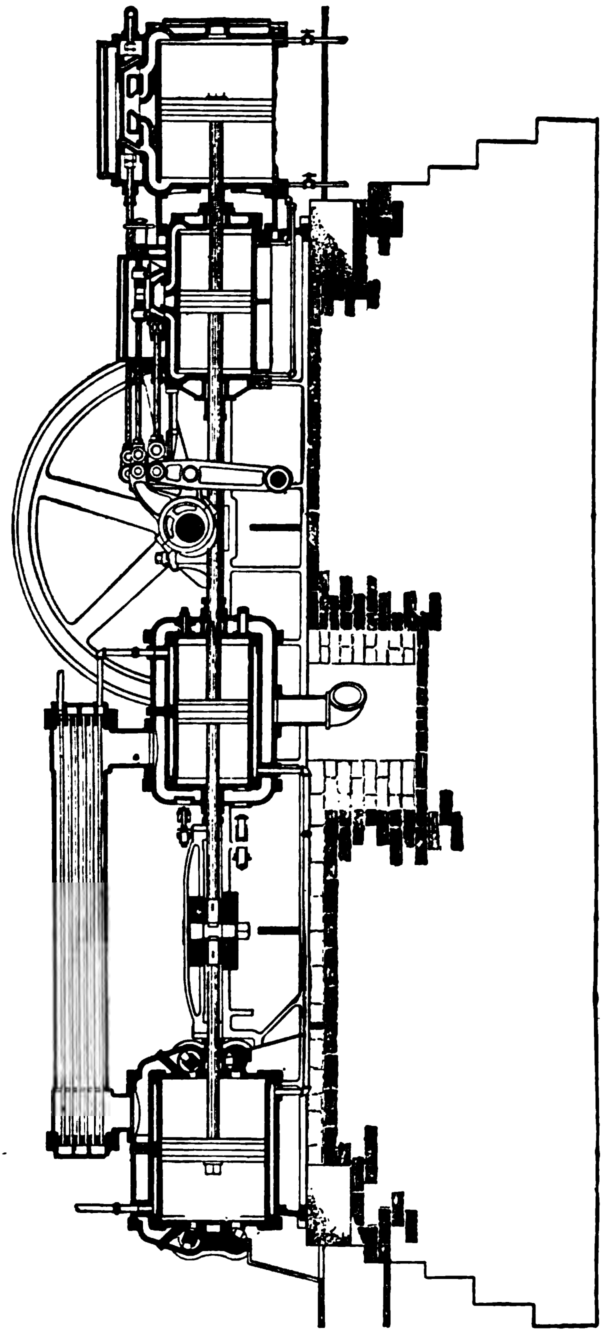


Fig. 82.

The Norwalk Compressor.—Two-Stage Air Compound Steam Cylinders, showing the Inter-cooler between the two Compressing Cylinders.

The necessary connections can be made at a merely nominal expense. The air conduit should be of wood. It should pass beneath the floor and communicate with the air ports by removable hoods. This method of taking air will, in summer, generally result in a gain of from 3 to 5 per cent, even when the cold water spray is not used. The gain amounts to 1 per cent for every five degrees that the air is taken in lower than the temperature of the engine room. In the winter forty to fifty degrees would be a very ordinary difference, and a proportionate gain would result from the outside connection. The inlet conduit should have an area equal to at least 50 per cent of the area of the air piston, and should be made of wood, brick, or other non-conductor of heat.

Metal should not be used in the inlet conduit, as it conducts heat from the cylinder and warms the air on its inward passage. Neither should the air be brought in contact with the cylinder head, or any surfaces or passages which are heated by the work of previous compression.

The air should arrive as cold as possible within the cylinder. This is secured only by admitting it in a solid, undivided mass through the shortest possible port.

The air is admitted to the cylinder by valves of the well-known Corliss steam-engine pattern, which have a positive movement from the main shaft. The port is large, is clear of obstructions, and opens directly into the cylinder.

The air is partially compressed in one cylinder; it then passes through an inter-cooler, where it is thoroughly cooled, and finally is compressed to the desired degree in the second cylinder. Both cylinders are surrounded by water jackets, and the inter-cooler is a large chamber filled with small copper tubes, through which cold water circulates.

No water is allowed in the cylinders in contact with the air, and all cooling is effected by surface coolers. Air is a poor conductor of heat, and in order to cool it thoroughly it is necessary not only that every particle be in turn brought in contact with the cooling surface, but that it also have sufficient time to part with its heat. Much cooling cannot be expected of simple cylinder jackets, because the air in the cylinder is in a large body, and has very little time to give up its heat between the successive strokes of the piston, and also because the advancing

piston rapidly covers up the jacket, and thus reduces its effective area. On the compound compressor there are two cylinder jackets, which should be credited with all the useful effect due to such attachment on any compressor.

In the inter-cooler is found every element for successful cooling. Here the air is divided into thin streams; it comes in contact with large surfaces, and is given ample time to cool.

PROPERTIES OF AIR.

A cubic foot of dry air at atmospheric pressure, and at any absolute temperature, weighs 39·819 pounds avoirdupois, divided by the absolute temperature.

TABLE OF WEIGHTS AND VOLUMES AT ORDINARY TEMPERATURES AT SEA LEVEL.

Temperature, Fahrenheit.	Pounds' Weight of One Cubic Foot.	Volume of One Pound in Cubic Feet.	Constant Difference.
0	·0863	11·582	1·256
50	·0779	12·838	·251
60	·0764	13·089	·251
70	·0750	13·340	·251
80	·0736	13·592	·251
90	·0722	13·843	·251
100	·0710	14·094	·251
110	·0697	14·345	·251
120	·0685	14·596	·251
130	·0674	14·847	·251
140	·0662	15·098	·251
150	·0651	15·350	·251

The table shows the desirability of always using the coolest air obtainable for compressors.

CHAPTER V.

ELECTRICITY.

BY GEORGE H. WINSTANLEY.

A QUARTER of a century ago there existed no such industry as electrical engineering. To-day it occupies a position in the forefront of the great engineering industry. Never before in the history of industrial development have such rapid strides been made, such remarkable progress recorded.

There is a close affinity between coal and electricity. Coal is, to all intents and purposes, the foundation of manufacturing industry; electricity in recent years has exerted a widespread influence upon those industries—some it has almost revolutionised. Coal, the chief source and store of energy; electricity, the means by which that energy may be transmitted and applied.

From the very first it was evident that electrical engineering was destined to play an important part in mining, the operations of which call for power in places far removed from where that power can be generated.

Electrical energy has at length even become officially recognised in mining legislation; and whilst this book has been going through the press, regulations have become law which prohibit our doing things we should never dream of doing, whilst leaving us at liberty to do things which ought to be prohibited.

There is, doubtless, a good deal about electricity which has yet to be discovered, but that will not serve as an excuse for ignorance of those principles which *are* open for our study, and which now, more than ever, must engage the attention of the colliery engineer.

In the following pages the writer, from the standpoint of the colliery engineer, has endeavoured to place these principles

before his readers; and, by avoiding involved technicalities, which are more for the electrical experts, trusts that he has, in some measure, succeeded in setting forth the more important of these principles in manner suited to the requirements of the majority of his readers.

A consideration of the work already accomplished by the many firms of electrical engineers who specialise in plant for colliery purposes will readily convince the reader that there can be little doubt as to the beneficial application of electricity in mining.

GENERATING PLANT.

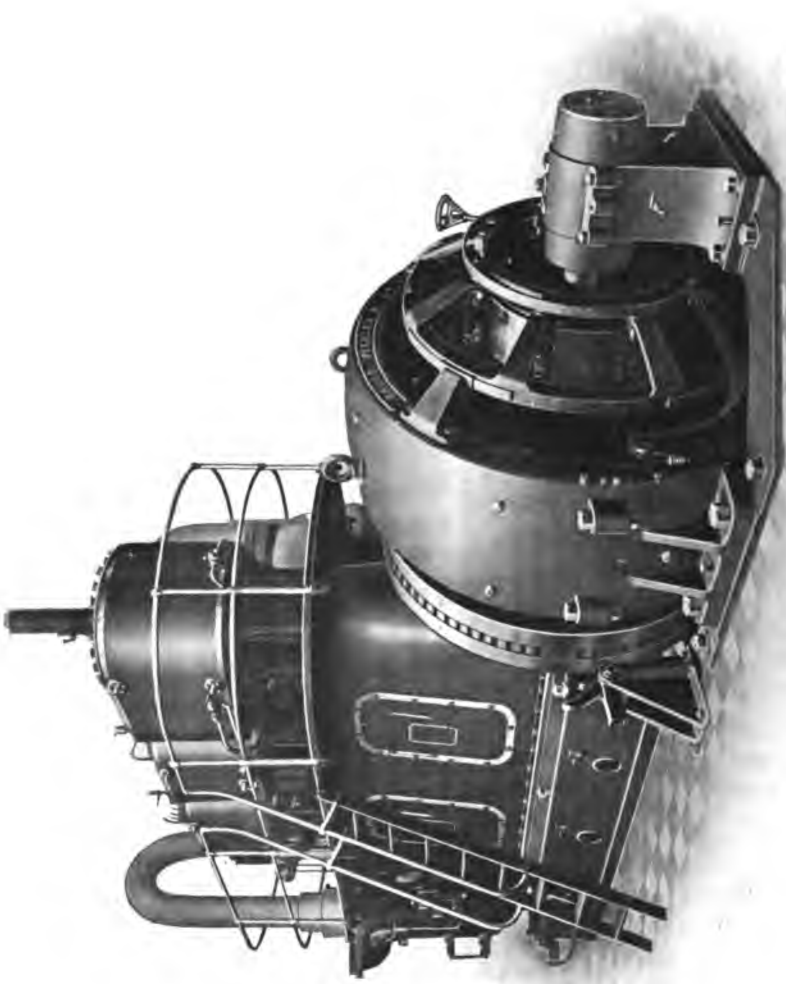
At the outset it will perhaps be useful to direct our attention to the generating plant, which in colliery practice will, as a general rule, be steam-driven.

The engines applied for the driving of electrical generators represent some of the best and latest developments in steam-engine practice. The electrical generator or dynamo is a machine which revolves at a fairly high speed, and formerly this high speed was obtained by means of a belt or rope drive from the engine. For small plants this plan is still to some extent adopted; but for anything from fifty kilowatts or upwards it is generally agreed that the direct-coupled, or engine type, of generator is the best.

The steam engines adapted for this purpose are represented by the productions of such well-known firms as Bellis & Morcom, Galloways, Mather & Platt, Alley & MacLellan, and Willans & Robinson. These are all of the high or moderately high-speed type, and attain a high degree of efficiency. They are arranged either as simple non-condensing, condensing, compound, and triple-expansion condensing, with a consumption of steam varying from thirty pounds per indicated horse power in the former type to twelve pounds in the latter.

As a rule, the vertical type appears to be the most popular, although the horizontal arrangement is frequently adopted.

Two essential features in engines for electrical generators are constant speed and freedom from vibration. The former is achieved with considerable success by means of ingeniously-contrived governing arrangements, and there appears to be no difficulty in obtaining engines which will run with no greater variation of speed than 1 per cent with a load variation of



A Direct-Coupled Continuous-Current Generator, Messrs. Bruce, Peebles & Co. Limited.

from no load to full load. Most of these engines, too, run with remarkable freedom from vibration in spite of the high speeds. A popular and pleasing test, which a prospective client is often invited to perform for his own satisfaction, is to stand a penny on edge on the cylinder cover of these engines whilst in motion, or a pencil may be stood on end to similarly indicate the steadiness of the engine.

Messrs. Belliss & Morcom Limited, of Birmingham, whom the writer believes to be the pioneers of the double-acting high-speed type of engine, have furnished some interesting particulars of their engines, with official tests made under actual working conditions. These tests demonstrate conclusively the reliability and efficiency of this type of engine. A system of forced lubrication is a special feature of the Belliss engine, which ensures the absolute lubrication of every bearing, thus not only reducing friction losses, but prolonging the life of the engine by reducing wear and tear to a minimum. The oil is dealt with by means of a simple type of pump, which delivers the lubricating medium into the distributing channels at a pressure of from 10 to 20 lbs. per square inch.

In the sectional illustrations, figs. 83 and 84 (*see pages* 164 *and* 165), the oil is seen below the crank, from where it is pumped into the bearings, afterwards draining back to be used over again. The governor appears on the right-hand extremity of the crank shaft in these two illustrations, the former of which is a compound engine with two cranks in straight line, and the latter a triple-expansion engine with three cranks, forming an angle of 120 degrees with each other.

A notable feature of the compound type is the simplicity of the arrangement, and the comparatively small number of working parts; the valve gear, for example, requires only one eccentric and rod.

Some interesting figures are given in the official reports of these engines at work in power stations in various parts of the country. In one case the engine is said to have worked without stopping from the 1st of July to November 30th, 85,000,000 revolutions. This engine had been running almost continuously, night and day, since May 1896.

Another instance worthy of special reference is that of a 250 horse power compound engine installed at an electrical

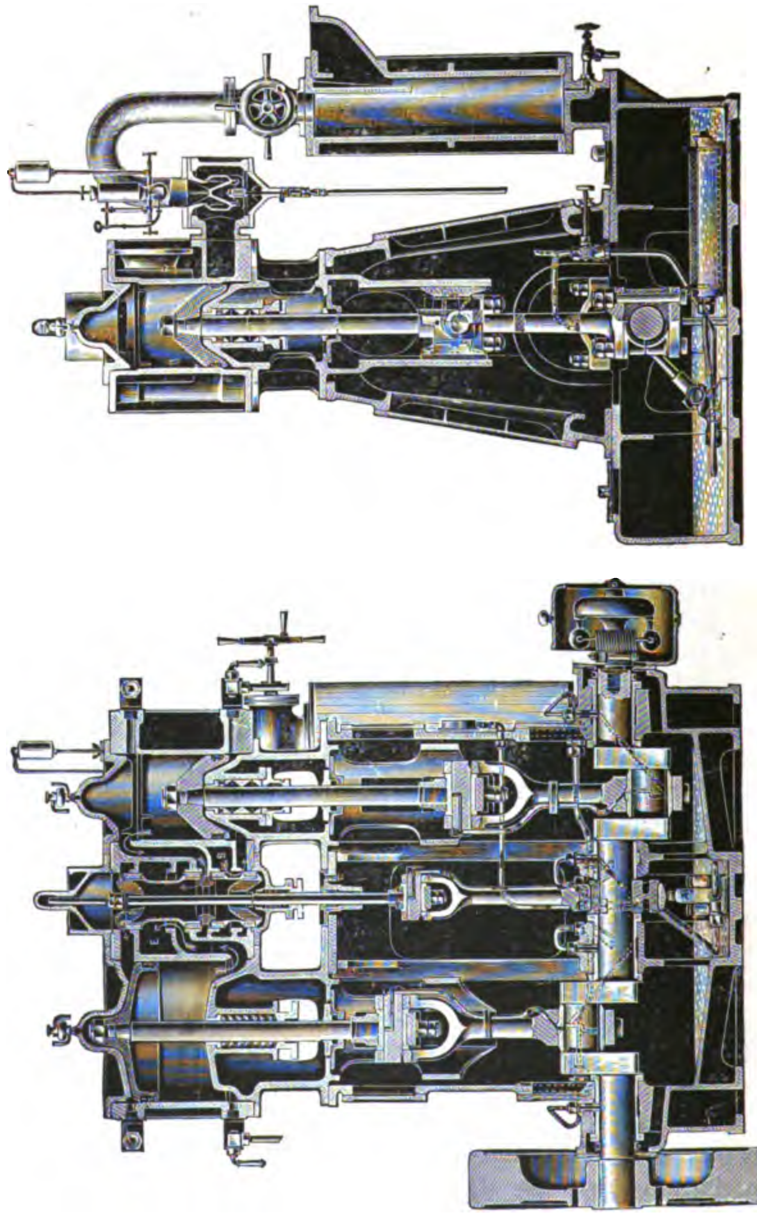


Fig. 88.—Sectional Drawing of the Belliss Compound Engine.

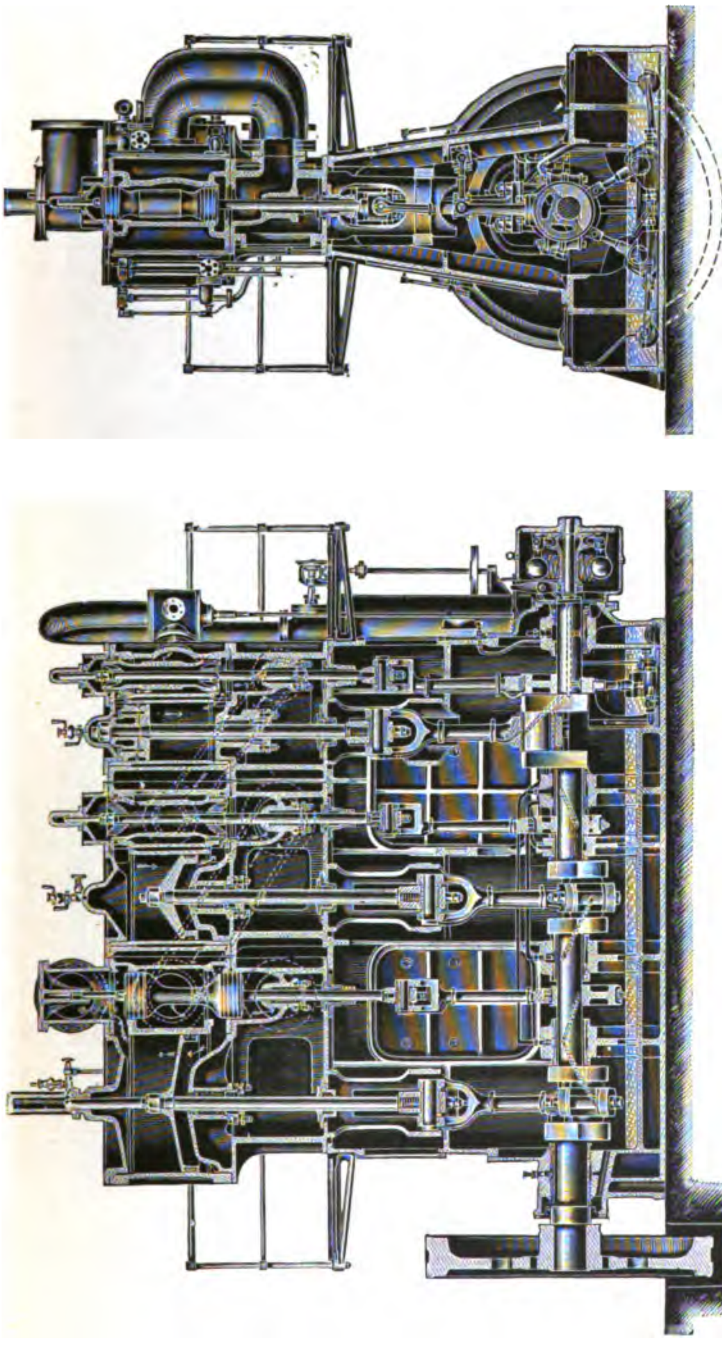
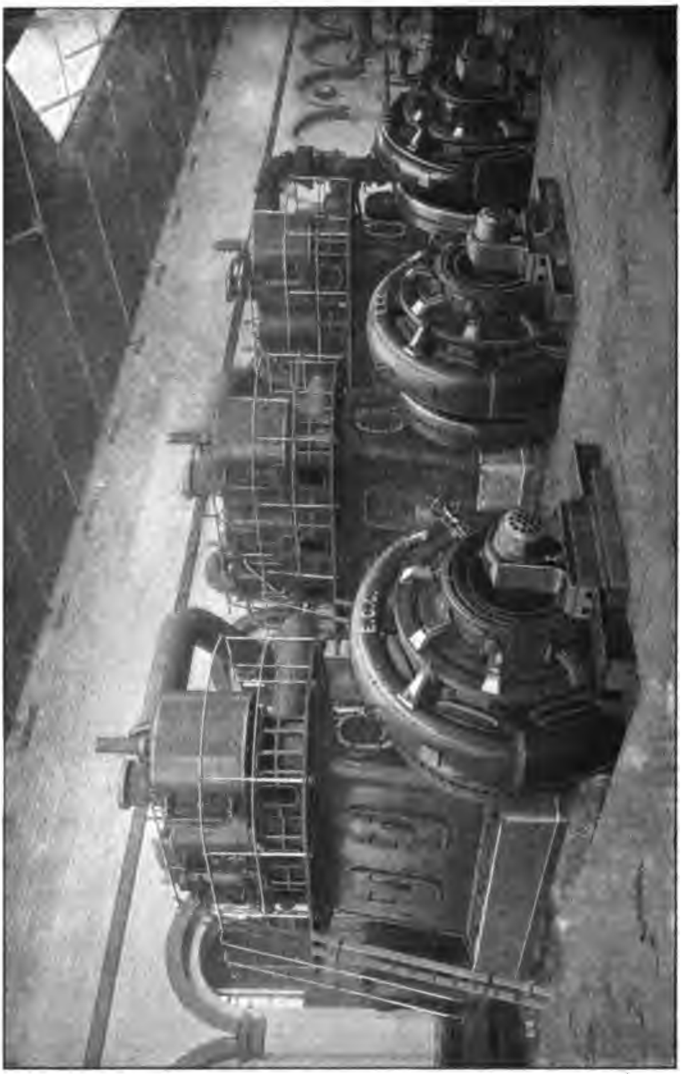


Fig. 84.—Sectional Elevations of the Belliss Triple-Expansion Engine.

generating station. After five and a half years' work official tests and measurements were made for the purpose of comparison with the tests made when the engine was first put to work. The



A POWER STATION WITH THREE BELLISS ENGINES, 1000 B.H.P. EACH.

result of the comparison was to show that, so far as the brake horse power developed, efficiency, and steam consumption were concerned, the engine was as perfect as when new; in fact, the

efficiency had actually improved with full load and under-load, as the following figures show:—

	New.			After Five and a Half Years' Working.		
	Full Load.	Three-quarters.	Half.	Full Load.	Three-quarters.	Half.
B.H.P. ...	218·4	162·	107·7	218·	162·	108·
I.H.P. ...	245·5	184·5	126·9	232·	173·	117·
Efficiency..	89· %	87·7 %	84·8 %	94· %	93·7 %	92·2 %

The steam consumption was found to be from 19·3 pounds per brake horse power per hour full load to 20·4 on half load. Speed 360 revolutions per minute.

The efficiency of the forced lubrication is demonstrated by the amount of wear as measured by means of micrometer gauges, viz.:—

Main bearings	about	·0025	inch.
High-pressure crank pin ...	about	·005	„
Low-pressure crank pin ...	about	·009	„
High-pressure crosshead pins		·0035	„
Low-pressure crosshead pins		·008	„
Eccentric sheave		·008	„
High-pressure piston rod		·011	„
Low-pressure piston rod		·005	„

As already remarked, an essential feature in an engine for driving an electrical generator is uniformity of speed under a varying load. The makers of the Belliss engine express themselves prepared to guarantee that the permanent variation of speed, between full load and no load, shall not exceed 1 per cent with a momentary variation of not more than 2 per cent. Figs. 85 and 86 (*see pages* 168 *and* 169) represent an excellent type of vertical high-speed engines made by Messrs. Galloways Limited.

In the direct-coupled arrangement an extension of the armature shaft is fitted with a half-coupling, and the end of engine crank shaft with the corresponding half. An arrangement to which Messrs. Bruce, Peebles & Co. have called our attention is perhaps even still better; there is an extension of the "spider" of the armature, which is bolted directly to the side of the heavy flywheel with which these engines are generally fitted. (*See fig.* 87, *page* 170.)

In the case of large alternators, the revolving portion of the generator is, to all intents and purposes, itself a flywheel. (*See fig.* 88, *page* 171.)

The absence of belts or ropes in the direct-coupled or engine-type arrangement is a distinct advantage, removing as

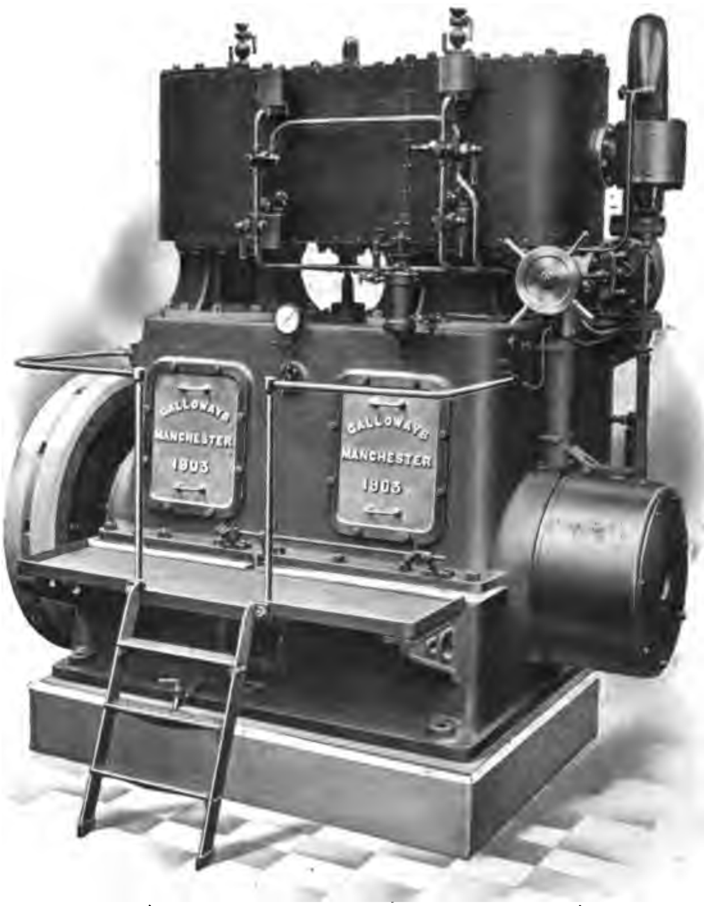


FIG. 85.

THE GALLOWAY COMPOUND ENCLOSED HIGH-SPEED ENGINE

it does a somewhat serious liability to breakdown. The plant is more compact, and a smaller or less expensive power house, with less costly foundations, will accommodate a plant of greater capacity. There is an entire absence of "back lash"

under sudden variations of load, a freedom from noise, and less trouble with dust and dirt—quite an important item in the management of a power house.

Mention has already been made of the steam turbine, a type of steam engine which would appear to have a particular application to electrical power plant. The simple rotary motion, free from variations of angular velocity, is exactly suited to the simple rotation of the generator. A good idea of a large turbo-generator is given in fig. 89 (*see page* 172), for which we are indebted to the

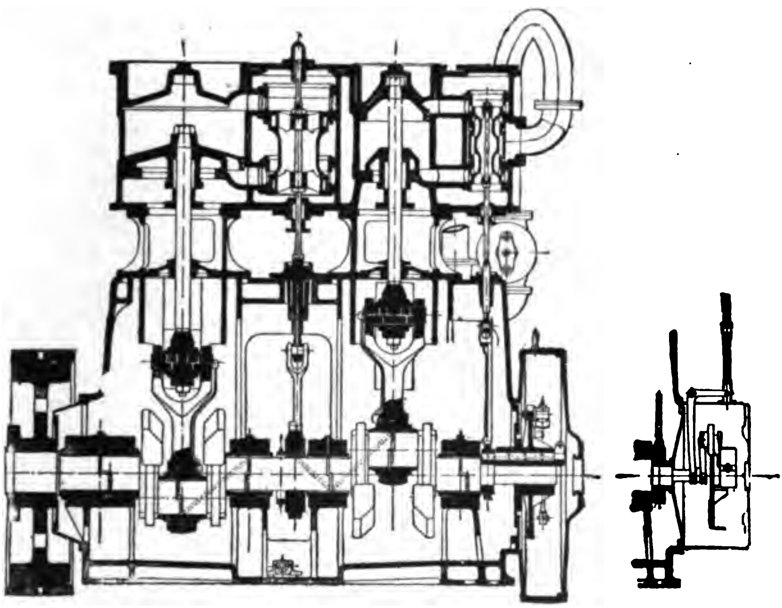


FIG. 86.

SECTION OF THE GALLOWAY COMPOUND ENCLOSED HIGH-SPEED ENGINE.

British Westinghouse Electric and Manufacturing Company. It represents one of four installed at the Metropolitan Railway Company's power station at Neasden by the British Westinghouse Company. The capacity of the turbine is 5000 brake horse power, and it is coupled to a three-phase alternator generating current at 11,000 volts 184 amperes per phase, from which we can calculate the capacity of the generator—184 × 11,000 × 1·73 equals, say, 3500 kilowatts. The guaranteed efficiency of the generator on full load is 96·5 per cent, and 93·75 per cent at half load. The speed is 1000 revolutions per minute.

Steam is supplied at 180 pounds, with 180 degrees of superheat, and the guaranteed steam consumption at full load is not more than 17 pounds per kilowatt hour, equal to less than 13 pounds of steam per electrical horse power hour.

As indicating the compactness of a turbo-generating set compared with an ordinary reciprocating engine type, it may be mentioned that at one of the power stations in Manchester there is a turbo-generator and a reciprocating engine set of the same capacity, and the *total* weight of the turbo-generator amounts to *less than the weight of the flywheel* of the reciprocating engine.

FIG. 87.

A CONTINUOUS-CURRENT ARMATURE, WITH BRUCE PEEBLES' EXTENDED "SPIDER" COUPLING.

High efficiency and extreme simplicity seem to be the distinctive features of the steam turbine. There are no pistons or other reciprocating parts, few wearing parts, no packing, and little lubrication. It is stated, on good authority, that there are in operation steam turbines with a full-load steam consumption of less than ten pounds per indicated horse power.

GAS ENGINES FOR ELECTRIC POWER PLANT.

The gas engine, also, has an extensive field of operation in electric power stations, and it is not improbable, in the near future, that the gas engine will figure as an important item in the equipment of the colliery. (*See fig.* 90, *page* 173.)

There are, indeed, at the moment, collieries where the waste combustible gases resulting from the manufacture of coke are utilised, with the aid of gas engines, for the generation of electrical energy.

At most collieries there is a considerable amount of small and inferior coal, which could probably be used to greater

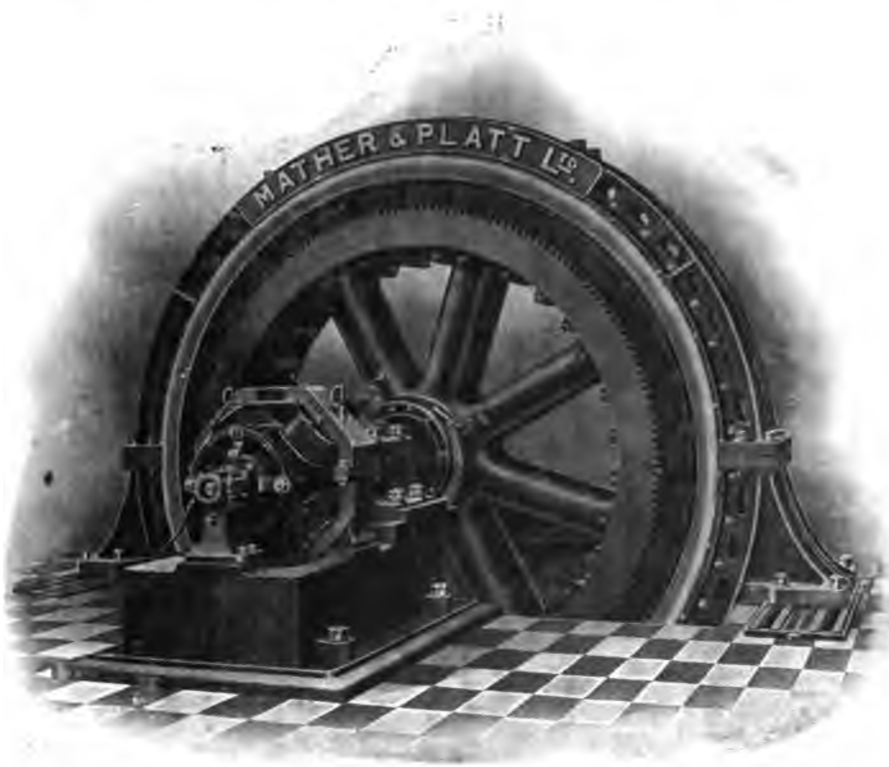


Fig. 88.
A Polyphase Alternator.

advantage in the gas producer than if consumed as fuel in the boiler furnaces.

A practice which has much to recommend it is that of dividing the generating plant, if large enough, into two or more units. An extra or stand-bye set is always desirable.

For example, take the case of a colliery where power plant

is required equal to, say, 500 horse power. It would probably be considered preferable to put down two 300 horse power units, or, better still, three 200 horse power sets. It will readily be seen that the full demand for power may not extend over the whole twenty-four hours, whilst half that amount may be required continuously, in which event one of the units may be put out of operation so long as the demand for power does not exceed the capacity of one unit. For 1000 indicated horse power full-load capacity it would be wise to install three sets of, say, 500 indicated horse power each.

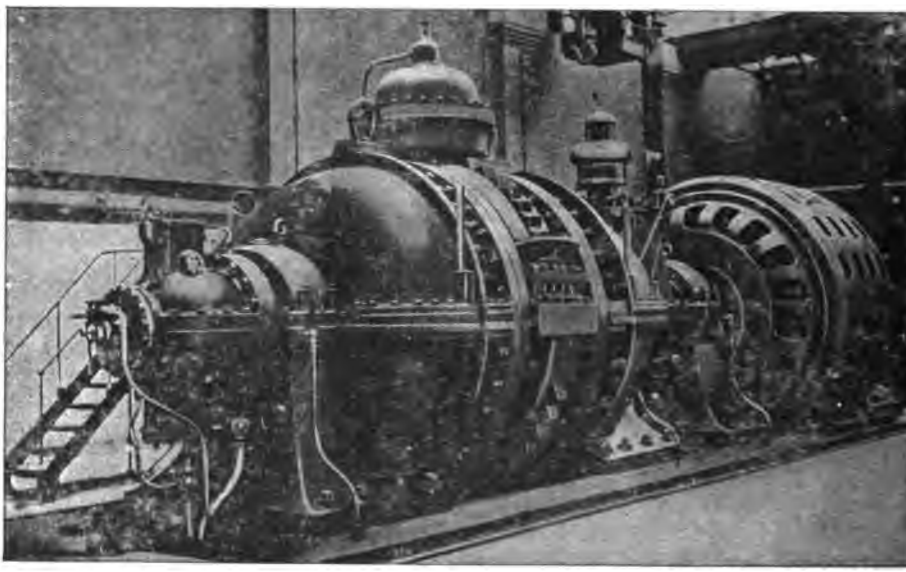


FIG. 83.

A 5000 B.H.P. WESTINGHOUSE TURBINE, COUPLED TO A 3500 K.W. THREE-PHASE WESTINGHOUSE ALTERNATOR.

A consideration of the more technical details of electrical applications is scarcely within the scope of this work, nor does the writer feel that he would be justified in attempting a task so entirely beyond his capabilities. Still, there are matters upon which one may venture to write without being accused of trespassing beyond the confines of the subject in hand; we have the experience of electrical engineers to guide us, and we

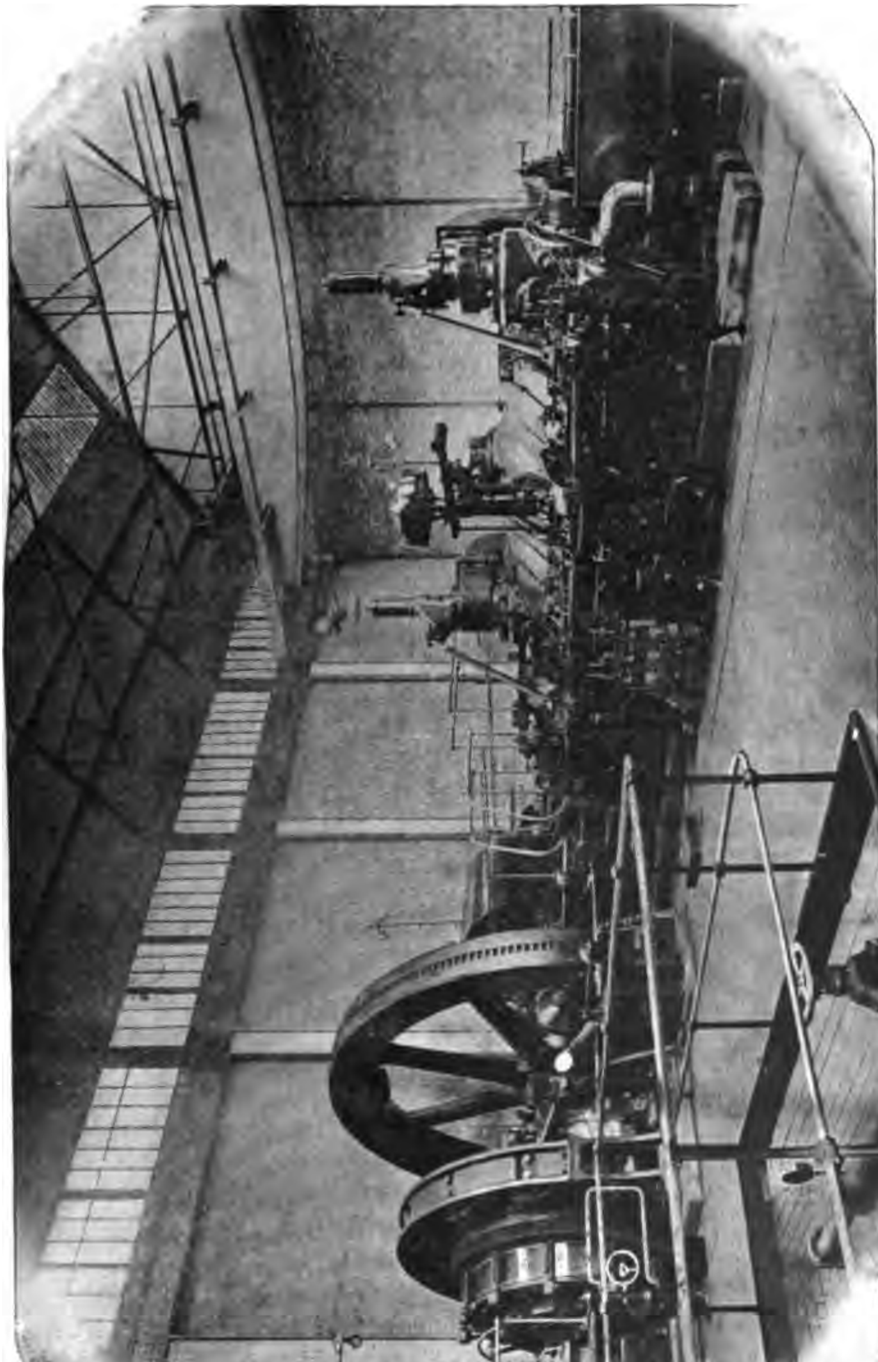


Fig. 90.—A 750 b.h.p. Two-Cycle Gas Engine, direct-coupled to a Continuous-Current Dynamo. Constructed by Messrs. Mather & Platt Limited, Manchester.

may, as mining men, consider from a mining standpoint the conditions which the electrical experts place before us.

DIRECT AND ALTERNATING CURRENT.

We may therefore, at this point, enquire into the relative advantages of direct and alternating current for colliery purposes. It is only comparatively recently that the application of alternating current has come to the front in connection with colliery engineering in Great Britain—the earlier examples of electrical power at collieries were all direct current; even more recently extensive and excellent examples of direct-current plant have been installed at British collieries. At the same time we are given to understand, by electrical experts, that the alternating current offers advantages for colliery purposes which demand the most careful consideration on the part of colliery engineers, advantages of which the importance cannot be questioned. How, then, are we to account for the fact that for a time the application of the alternating current appeared to have been overlooked, or indeed such application considered impracticable?

In the first place, it may be at once admitted that the simple alternating current is not suitable for power transmission in collieries. The reason need not be gone into here, except that it may be mentioned there are difficulties connected with the starting of simple alternating-current motors which would render their application for such purposes as colliery haulage almost impossible. It is true that considerable progress has been made recently, in connection with single-phase motors, but the development has not yet reached the point when they can be adopted by the colliery engineer.

In the second place, it ought to be explained that the one form of alternating-current motor specially suited for colliery work—the three-phase motor—was for a time hedged round with legal difficulties and complications in the law of patents, which retarded its progress and stood in the way of its adoption in this country, leaving the field open for the continuous-current motor.

Now, however, these difficulties and restrictions no longer exist, and there can be little doubt as to the immense value of

the three-phase alternating current, and the polyphase motor, for power transmission and distribution in mines.

Turning, then, to the advantages of the polyphase system, it may be remarked with regard to the generating plant, that the steam turbine can be more successfully applied to the alternating-current generator than to the continuous-current. With the latter there are difficulties with the commutator and collecting brushes at the very high speeds common to steam turbines. In the former these difficulties are absent, for the simplest of reasons—namely, that the commutator and brushes are themselves absent.

The construction of the alternating-current generator is simpler than the continuous-current type, both mechanically and electrically.

In the continuous-current generator the armature—the rotating portion of the machine—carries at the full voltage practically all the current generated, and it is difficult to protect the windings, both electrically and mechanically. In the alternating-current generator on the other hand, as a rule the field magnets constitute the rotating element, and the high voltage current is confined to the stationary windings, which connect with the distribution line directly, and not through a commutator and brush arrangement.

Perhaps no stronger recommendation need be given in favour of the three-phase system than the fact that it has been adopted by practically all the large electrical power supply companies, who must have the questions of reliability and economy ever before them.

With continuous current it is not practically possible to generate current at a higher voltage than 650, and whilst this might be considered quite high enough for actual application in the mine, we may often be called upon to consider the advantages of higher pressures for long-distance transmission, and the alternating-current machine makes it quite possible to generate current at a much higher voltage. There are, as a matter of fact, many cases of alternating current generated at 11,000 volts.

A considerable item in the outlay for electrical power transmission plant is the cost of the cables, and it is in this connection that the three-phase alternating current shows to

advantage in the higher pressures. There is little or no difference in the two systems when working at the same pressure, although the three-phase transmission requires three cables whilst the continuous current only requires two; the amount of copper, however, is about the same—perhaps slightly more for continuous than for three-phase. Where, however, the distance to be covered by the transmission system is considerable, and the actual transmission of the current is at a high pressure, the high efficiency and economy of the three-phase system becomes evident.

Take as an example a simple case. It is desired to transmit electrical energy to a number of motors having a total capacity of, say, 100 brake horse power, at a point 2000 yards away from the generator. This is to be effected either by continuous current at 500 volts or alternating current at 3000 volts. The same current density in the cables is assumed in both cases—namely, 1000 amperes per square inch sectional area of the copper. The efficiency of the motor is also taken as the same in each case—namely, 86 per cent.

In the continuous-current case the loss in the cables due to drop in voltage—100 volts—would amount to 20 per cent, which, together with the motor efficiency of 86 per cent, would give a combined efficiency of 68·8 per cent, requiring an output of 145½ electrical horse power from the dynamo to give the required 100 brake horse power from the motors.

In the alternating-current case the drop in voltage will be 120 volts, or a loss of 4 per cent. It will also be necessary to employ transformers at the motor end of the system to reduce the high voltage to one more suitable for the motors; the transformers will account for a further loss of 3 per cent, or a combined efficiency for cables, transformers, and motors of 80 per cent, requiring an output from the generator of 125 electrical horse power, as against 145½ electrical horse power in the first case.

The cost for cables and transformers for the three-phase system would be about £400, whilst the cables for the continuous current would cost little short of twice as much—namely, £750.

The initial cost of the plant, generators, and motors, etc., would be considerably in favour of the polyphase system.

Whilst recognising what appear to be the advantages in connection with alternating current, the fact remains that

electrical firms still continue to make and supply continuous-current machinery to an extent which does not seem to indicate that the polyphase system will immediately and entirely supplant the continuous current. Most electrical manufacturing firms of repute make both classes of generators and motors, and the general excellence of each will be admitted by those who carefully examine the productions of these firms. The writer holds no brief either for the one or the other, but must confess to a leaning in the direction of alternating current.

THE ALTERNATING-CURRENT GENERATOR.

In the search for reliable matter with which to illustrate

FIG. 91.
THE ROTATING FIELD OF A WESTINGHOUSE ALTERNATOR, READY TO RECEIVE THE COILS.

this section of the work, the writer has been fortunate in securing the assistance of the British Westinghouse Electric Manufacturing Company Limited, whose immense works in

Trafford Park, Manchester, have afforded him more than one opportunity of enquiring closely into the construction of electrical machinery of the highest possible standard of excellence.

The British Westinghouse Company have placed at our disposal quite a large amount of valuable information, which has been made use of in the compilation of these pages, together with a large number of illustrations, showing electrical machines and parts of electrical machines, calculated to be of the greatest service in explaining many of the principles with which the reader will desire to become familiar.

FIG. 92.
WESTINGHOUSE ALTERNATOR.—THE ROTATING FIELD, COMPLETE WITH COILS AND SLIP RINGS.

Fig. 91 (*see page* 177) and fig. 92 serve to explain the construction of the modern alternator with a rotating field magnet. Fig. 91 shows the revolving magnet before the magnet coils are fitted. The pole pieces, like huge teeth, are built up of sheets of thin steel, and secured to the circumference of the flywheel. The two metallic rings seen on the end of the shaft (fig. 92) serve as a means of contact for the low-pressure continuous current to excite the field magnets. The coils are now shown in position,

and the two rings represent the terminals of those coils. The alternator is a separately-excited machine, and the continuous current necessary for this is generated by a small dynamo, which is sometimes coupled to an extension of the main shaft, and delivers the current to the two rings by means of two sliding contacts or brushes, one for each ring—the positive and negative, in fact.

FIG. 93.
THE STATIONARY ARMATURE OF A WESTINGHOUSE ROTATING FIELD ALTERNATOR.

The field magnet revolves within the armature, fig. 93, in the windings of which the alternating current is induced, and this is taken directly from the machine by the fixed terminals, of which, in a three-phase alternator, there are three.

THE CONTINUOUS-CURRENT GENERATOR.

For continuous current, the generator used for a colliery

power plant would, as a rule, consist of a dynamo direct-coupled to the engine, and would answer to the description of a multipolar compound wound machine—multipolar because, instead of one field magnet with two poles, there are several magnets, each with two poles. The types usually installed have either four, six, eight, or ten poles, according to the size of the machine.

The compound winding—a term which refers to the particular method of winding the field magnet coils—enables the generator to maintain a constant voltage under varying loads. As a matter of fact, the dynamos used for colliery power plant are generally *over-compounded,* an arrangement which causes the voltage to slightly increase with an increased load, with the object to be made clear later.

It is assumed the reader is aware that the field magnets constitute the fixed and outer portion of the continuous-current dynamo, the revolving portion being the armature. The armature is usually of the drum-wound type, the drum consisting of a large number of thin, soft sheet steel punchings built up on a spider. Longitudinal parallel slots in the surface of this drum receive the insulated windings, in which the current is induced by the influence of the magnetic field upon the revolving armature.

The ends of these windings are connected with the copper bars which constitute the commutator. The latter is a highly important element in the construction of the continuous-current dynamo and motor, and one calling for the greatest degree of mechanical perfection and excellence of workmanship; not that other portions of the machine call for less, but because the commutator is, in a faulty machine, one of the parts to give most trouble. It is built up of heavy bars of copper, all most carefully adjusted, and each bar separated from its fellows by means of mica. The whole is truly turned, accurately finished, and securely mounted on the armature shaft or spider, from which it is electrically insulated.

The brushes—usually blocks of specially-prepared carbon—equal in number the poles of the machine; for instance, a six-pole generator will have six brushes, each bearing lightly upon the cylindrical surface of the commutator at equidistant points. These serve to collect the current, and are suitably connected with the terminals of the machine.

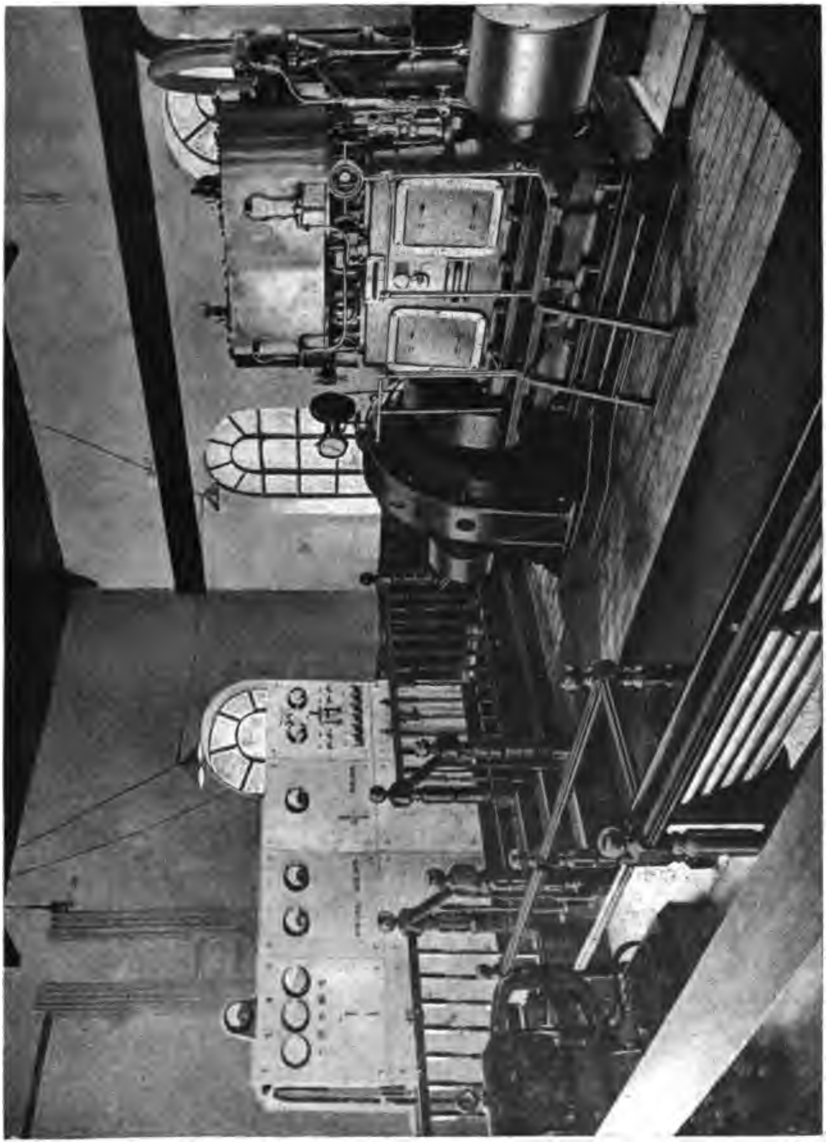


FIG. 94.—A COLLIERY ELECTRICAL POWER HOUSE (THE CORLETT ELECTRICAL ENGINEERING COMPANY LIMITED, WIGAN).

A well-designed continuous-current generator is generally specified to safely withstand an overload of 25 per cent for half an hour or an hour, and a momentary overload of 50 or even 100 per cent. It should run sparklessly with a fixed brush position at all variations of load from no load to 25 per cent overload.

MOTORS.

Coming now to the motors, we find in the three-phase motor a machine eminently adapted for colliery purposes. Both mechanically and electrically it is exceedingly simple, and

FIG. 95.

THE ROTOR OF A 150 HORSE POWER WESTINGHOUSE POLYPHASE MOTOR. SHORT-CIRCUITED OR SQUIRREL-CAGE TYPE.

possessing neither commutator nor brushes, there is an entire absence of sparking, whilst the liability to breakdown is less than in the continuous-current motor.

Here, again, as in the alternating generator, the rotating portion of the machine is of the simplest character, and singularly free from any tendency to develop defects. It may be explained that the revolving portion of the three-phase motor, called the rotor (fig. 95), has no connection whatever with the external circuit; that is to say, there is no connection between the cables carrying the current to the motor and the rotor windings.

The rotor revolves within the stationary windings of the

stator (fig. 96), and these stationary windings alone are in connection with the cables.

There are in general use two types of polyphase motors, the "squirrel-cage," or short-circuited type (fig. 95), and the wound rotor with slip rings and external resistances (fig. 100, *see page* 187). The former represents the simplest contrivance imaginable for the conversion of electrical energy into mechanical work. The revolving element, the rotor, consists of a drum or cylinder built up of soft steel discs, round the circumference of which

FIG. 96.

THE STATOR OF A THREE-PHASE MOTOR, WITH THE WINDINGS IN POSITION IN THE SLOTS.

are punched openings or holes. When the discs (or, in the larger sizes, rings) are assembled to form the drum or cylinder, the openings form longitudinal parallel slots into which insulated copper bars are fitted. The extremities of the bars are connected by bolts or set screws to copper rings, one at

each end of the drum. The whole is keyed upon a suitable shaft, or upon a spider, in the manner illustrated in fig. 95 (*see page* 182).

The outer or stationary portion of the machine, called the stator, is also built up of laminated rings of sheet steel, forming a hollow cylinder, and similarly slotted on the inner surface (fig. 97) to receive the insulated copper wire or strip which forms the winding. The whole is contained within a suitable

Fig. 97.
The Stator of a Westinghouse Polyphase Motor, without the Windings, showing the Slots.

cast-iron casing. The fixed or stator windings alone carry the current from the power circuit, and there is consequently no commutator nor sliding contact needed, an entire absence of sparking being the result. Furthermore, it will readily be seen that, as these windings are stationary, it is a simpler matter to secure and protect them, both mechanically and electrically.

This type of motor (the squirrel-cage) has been largely and successfully applied for colliery purposes—hauling, pumping, etc.—and would appear to be admirably suited for all the usual

FIG. 98.
A LARGE WESTINGHOUSE SHORT-CIRCUITED POLYPHASE MOTOR, 850 HORSE POWER.

colliery operations, unless the circumstances are exceptional, and considerable variation of speed is desired, or starting under *unusually heavy* loads. For ordinary cases, however, even with considerable loads, we have seen these short-circuited or squirrel-cage motors started up without the slightest difficulty. This fact is mentioned because it is sometimes alleged, as an argument against polyphase motors, that difficulty is experienced in starting under load. The real difficulty is that

FIG. 99.
A THREE-PHASE SLIP-RING MOTOR. (The slip rings are shown on the right.)

in starting the short-circuited motor takes an excessive current, which, in the larger sizes, might interfere with the working of other motors on the same supply. For this reason the slip-ring type of motor is more generally used. Nevertheless, wherever possible, for colliery purposes we advocate the adoption of the squirrel-cage motor. This short-circuited type of motor is made in all sizes from about 5 horse power to 2000 horse power. (*See fig.* 98, *page* 185.)

The second type of polyphase motor is the slip-ring or external-resistance arrangement (fig. 99). In this case the ends of the

insulated windings are not short-circuited by permanent attachment to copper rings, as in the squirrel-cage type, but are coupled up to rings, insulated from the machine and from each other, occupying a somewhat similar position to the commutator of the continuous-current machine. (*See fig.* 100.) In a three-phase motor there are three of these rings. Sliding contacts or brushes bear upon the rings, serving as a means of connection with an external resistance. The object of this arrangement is to insert a gradually-decreasing resistance, controlled by the starting switch, in the current induced in the motor windings when starting the motor.

As the motor speeds up the resistance is gradually cut out until finally the rotor windings are short-circuited, and the

FIG. 100.

COMPLETE ROTOR OF A LARGE WESTINGHOUSE SLIP-RING THREE-PHASE MOTOR.

resistance may be disconnected. There is, of course, no liability of sparking at the slip rings since they are continuous, not built up of insulated bars as in the continuous-current commutator.

It is claimed that this type of polyphase motor is especially

suitable for working at variable speeds, and where machines have to be started against very heavy loads.

DIRECT OR CONTINUOUS-CURRENT MOTORS.

For colliery purposes these are frequently of the enclosed type—that is, the motor is contained in a casing more or less gas-tight, having regard to the possible presence of inflammable gas or dust in the neighbourhood of the motor. It is true that modern direct-current motors, carefully constructed, are comparatively free from sparking at the commutator; but the possibility is always there, and where there is the slightest risk of gas or dust the motor should therefore be of the enclosed type.

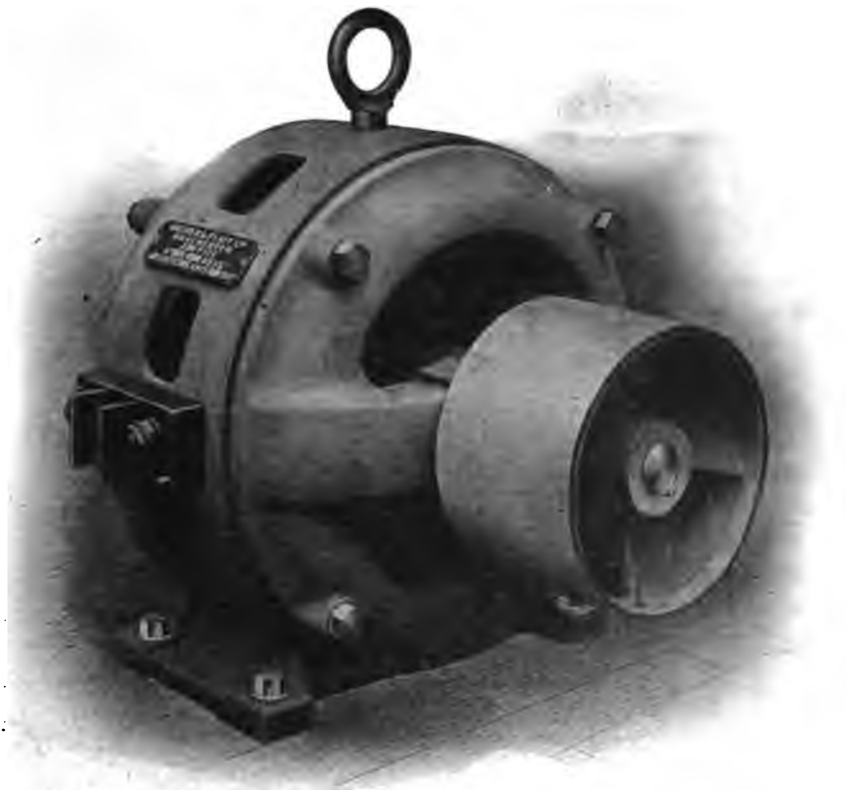
Unfortunately, however, this boxing up of the motor—an unnecessary provision in the three-phase machine—introduces a difficulty. All electrical machines—generators and motors—when working under full load tend to increase in temperature, consequent upon the conversion of a small fraction of the electrical energy passing through the windings of the machine into heat. The dissipation of this heat is usually provided for in the construction of the machine by forming air ducts and openings in the revolving portion, which cause a current of air to ventilate and cool the machine. If, however, the motor is entirely boxed up the air enclosed in the casing soon becomes heated itself to the temperature of the machine, which may, as a result, finally attain a temperature so high as to injuriously affect the insulation. To obviate this an enclosed unventilated type of motor is generally worked at a lower load than would represent its capacity if open and ventilated; in other words, a motor would be provided which was somewhat above the actual maximum load at which it would be worked. For example, the motors applied to electrical coal-cutting machines must of necessity be enclosed, and they must be capable of running under normal load without heating, or even for a short time with an even load without developing a high temperature.

Practically all the current delivered to a continuous-current motor passes through the revolving armature windings, which, forming portion of an arrangement rotating at a high velocity, up to 800 or 1000 revolutions per minute, or even more, are liable to be displaced through centrifugal force and injured.

The insulation, too, of the armature windings is liable to break down.

Makers of electrical machinery for collieries appear to have given greater attention to these points latterly, and there is a marked improvement in the continuous-current motors.

The brushes and commutators require careful attention and to avoid sparking must be kept in perfect condition; indeed, it



MESSRS. MATHER & PLATT'S "STEEL-CLAD" MOTOR.

may here be said that it is most important that *all* electrical appliances should have careful attention, and be kept in perfect condition. There is too often, in colliery practice, a tendency to neglect little defects until they have become serious and costly to repair. The time and trouble spent upon the electrical equipment, in keeping everything in perfect condition,

will be amply repaid by high efficiency and freedom from serious breakdown, whilst prolonging the life of the appliances.

Modern continuous-current motors are fitted with carbon brushes of ample area, and the machine designed to run sparklessly under considerable variations of load, but the liability to sparking at the commutator is always present, and nothing will develop sparking sooner than neglect.

Direct-current motors are series wound, shunt wound, and compound wound. For general colliery use—for hauling and pumping—the latter would appear to be the most useful of the continuous-current type. Shunt-wound motors are also used for hauling and pumping; the series-wound motor is specially suited for coal cutters.

Motors used for colliery purposes should be specified to stand an overload of, say, 50 per cent for a short time, and a momentary overload of 100 per cent without injury. They should also be capable of running sparklessly, with a fixed brush position, with any variation of load from no load to 25 per cent overload.

APPLICATIONS OF ELECTRICITY.

Electrical energy may be employed in connection with colliery operations for a variety of purposes. In a work of this character, reference to shot firing and electrical signalling, the use of telephones, and electrical re-lighting of safety lamps, is almost unnecessary—their advantages are too well known by this time to enlarge upon them now. We are concerned rather with the electrical transmission of power for the purposes of winding, haulage, pumping, ventilation, coal cutting, and motive power generally.

Mention might be made of the employment of electricity underground for lighting. The present writer's opinion is, that with suitable appliances and reasonable care, electrical lighting of mines ensures the nearest possible approach to absolute safety, so far as the ignition of inflammable gas is concerned. A detailed consideration of electric lighting, however, would be out of place here, and we may at once turn our attention to the applications of electricity for motive power.

WINDING.

Until comparatively recently it was difficult to see where lay

the advantage in employing electrical energy for colliery winding. The idea which naturally presented itself to one's mind was this—if we are to employ steam to drive an engine, the engine to work a dynamo, the dynamo to supply current to a motor, and the motor finally to operate the winding gear, where was the advantage? Why not at once apply the steam engine for winding, and save the intermediate operations?

The direct application of electrical energy on the simple lines suggested above would no doubt compare unfavourably with a modern high-class steam winding engine.

The colliery winding engine, however, even the most perfect type, is at the best very wasteful in steam consumption, and the *best* recorded results show a steam consumption of 65 pounds per horse power hour on the rope, and this with compound condensing engines and superheated steam. The average steam consumption of colliery winding engines is more nearly 200 pounds per horse power on the rope.

This extraordinarily high steam consumption is not due to any defect or imperfection in the engine itself, but is the result of the peculiar nature of the work the colliery winding engine is called upon to accomplish—totally unlike the conditions under which any other steam engine has to work.

Briefly, what the winding engine has to do is this—it has to start from rest, and *in a few seconds* to impart to a mass of material amounting to 100 tons, or even more, a high velocity, it may be of 60 miles per hour.

To overcome the inertia of this great weight, and to impart so high a velocity in a few seconds is an operation calling for the expenditure of an immense amount of energy—that is, in comparison with the useful work accomplished in merely raising the load. The unfortunate feature in the operation is, that after this large amount of energy has been stored up in the drum, cages, and other moving parts, it has to be deliberately wasted by the application of the brake, which is used to bring the engines to rest a minute or half a minute only later than the moment of starting. This is where the great loss comes in, and this is the direction in which at least one system of electrical winding has succeeded in effecting a remarkable reduction in steam consumption.

The system referred to—the Peebles-Ilgner arrangement—

is one in which there is no wasting of energy by the application of brakes, a system in which the intermittent steam engine, of considerably greater capacity than its average load, is replaced by a continuously-running engine with little or no variation of load, and therefore one with considerably higher efficiency. The arrangement consists of a winding drum or drums direct coupled to a continuous-current motor. This motor receives its electrical energy from the dynamo of a motor generator, called by the makers the compensating set, which consists of a motor taking current either from the mains of a power supply company or from the colliery generating plant, a generator to supply the winding motor, and a heavy flywheel of 30 or 40 tons between the two. To quote Mr. Maurice Georgi, who recently gave a most interesting description of this system in a paper read before the Manchester Geological and Mining Society (part xvi., volume xxviii.): "This heavy flywheel is the crux of the whole situation."

Principle of the System.—This system is based on the simple fact that a continuous-current motor, with a full and constant excitation—that is to say, running in a constant magnetic field,—will run at a speed varying directly in proportion to the electro-motive force of supply. Thus it is obvious that if a motor is wound up to run at 250 revolutions when supplied with 250 volts, it will run at 500 revolutions when supplied with 500 volts; therefore, if we arrange that this motor is fed by a continuous-current dynamo with independent excitation, whose voltage we can regulate from zero to a maximum by means of altering the excitation of this dynamo, then a motor driving from such a dynamo will run at a speed varying from zero to the maximum, depending on the voltage of the dynamo which drives it. It will thus be seen that when we start the machine we reduce the excitation of the dynamo, so that at starting the voltage is low, consequently the speed of the motor is low, and we gradually increase the speed to a maximum by altering the excitation of the dynamo, so that no serious resistance of any nature is required, and the motor starts up in the most economical manner possible.

The torque required at any moment is, of course, proportional to the current. The voltage multiplied by current represents the energy consumed, so that as the voltage is at a minimum at starting, the energy at starting is also the minimum.

CONSTANCY OF LOAD ON SUPPLY.—Now it is evident that this method of arranging the speed, as will be seen, is economical as regards starting; but we have to remember that, assuming the generating dynamo were either directly coupled to a prime mover or steam engine, or that the power were taken from a supply company through an ordinary motor generator, it is obvious that there would be considerable fluctuations in the supply, or in the running of the prime mover, due to the fact that the amount of energy taken at different periods of a complete wind vary considerably.

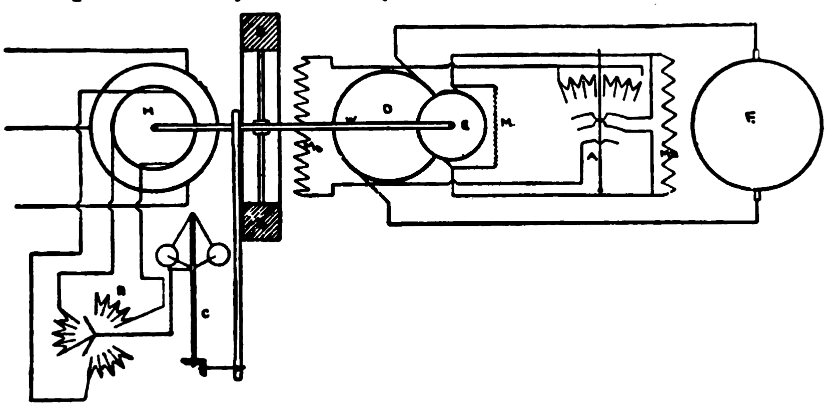


FIG. 101.
DIAGRAM OF THE PEEBLES-ILGNER ELECTRIC WINDING SYSTEM.

In order to compensate for these variations of energy in the Peebles-Ilgner process the following arrangement is adopted:—

The current from the supply, which may be either from a public supply company or from the collieries' own generating station, drives a special converter, which consists of a motor (H), a continuous-current dynamo (D), and a heavy flywheel (S) fixed intermediately between the two. (*See fig.* 101 *and fig.* 102, *page* 194.) The current from this continuous-current dynamo drives the main winding motor (F).

This heavy flywheel is the crux of the whole situation. It is the easiest method yet known of storing energy, and by the kinetic energy therein stored we can compensate absolutely for the variations in energy required by the winding gear itself.

A practical proof of the absolute compensation of this heavy flywheel can be seen by watching the measuring instruments on the supply circuit and on the main winding motor. The instruments on the winding motor may vary from zero to the maximum

during a complete wind, whereas the ammeter on the supply circuit remains absolutely steady, the whole variations being taken up by the flywheel of the motor generator.

RETARDATION—RECUPERATION OF ENERGY.—We will now assume that the machine is running at full speed, corresponding to the maximum voltage. If we diminish the excitation of the generator of the motor generator by means of the shunt resistance, the voltage of the generator will drop, but that of the motor driving the drum remains the same, so that the current will go from the motor to the dynamo. The winding gear is thus economically stopped as the recuperated energy is sent from the dynamo through the flywheel and motor back into the supply mains.

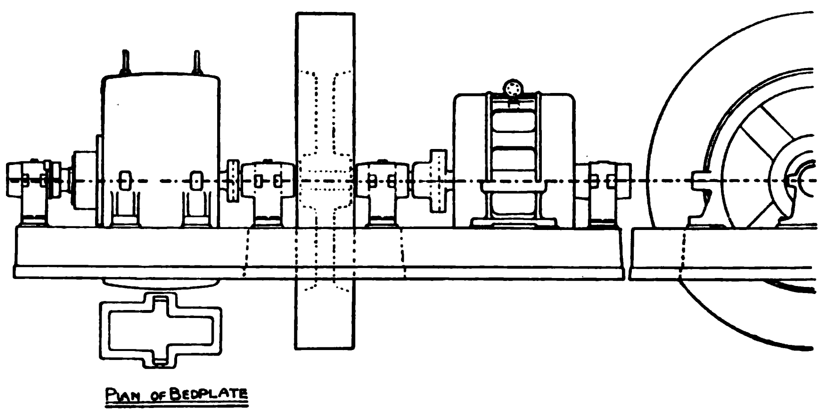


FIG. 102.
THE MOTOR GENERATOR OR COMPENSATING SET.

Brakes are employed, but simply in cases of emergency or for stopping the machine suddenly; they are not used for gradually bringing the machine back to rest, which is done by the retarding apparatus.

The machine thus recuperating energy, it is indifferent if the deadweight is badly balanced, for if at the beginning of the haul a strong current is necessary to overcome the momentum on the drums, the same, at the end of the wind, will have become negative, and will be driving the motor, thus sending energy back into the line. The size of the flywheel is independent of an unbalanced rope.

The current from the generator of the motor generator is carried direct to the winding motor without any intermediate fuses. In this manner no sudden stoppage of the electric supply

to the winding motor is likely to occur; the safety appliances are really unnecessary, as the machine cannot be overloaded, and a short circuit, due to defective winding, is always noticeable immediately. The field magnet current is produced by a small dynamo on the shaft of the motor generator.

It may be seen from this that the actual economy of the system is very high. This is accounted for by the fact that no starting resistances are used, and that the recuperated energy at any time is sent back into the line; also that the working factor of the flywheel is nearly equal to unity.

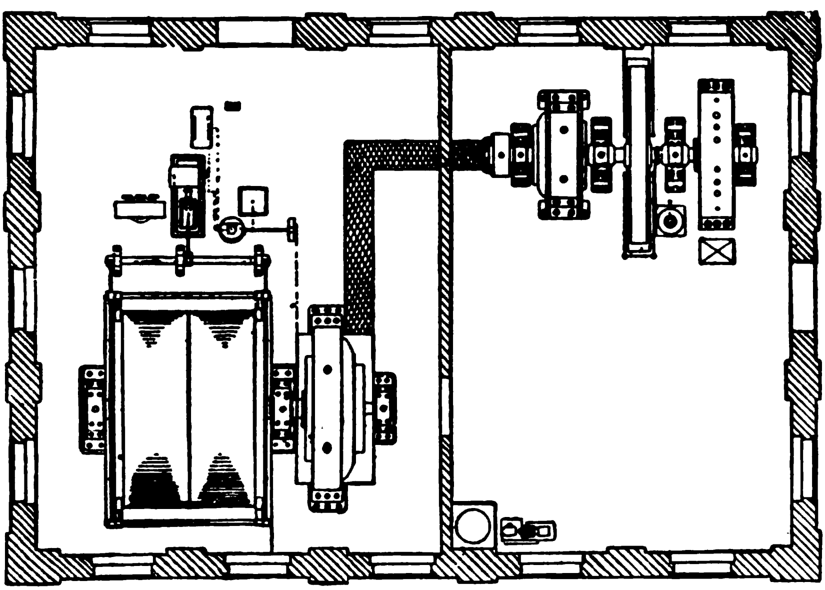


FIG. 103.

GENERAL ARRANGEMENT OF SYSTEM.—The driving gear may be of any type desired by the engineer. Whatever type he has been most familiar with for steam winding gear can be adapted to the electric motor; there is no limitation whatsoever as regards this. (*See fig.* 103 *and fig.* 104, *page* 196.)

The main motor (F, fig. 101, *see page* 193) is directly coupled to the winding gear. Direct coupling involves slight additional expense in the cost of the motor, but is strongly to be advocated on account of smoothness in running and freedom from vibration, and efficiency.

This motor is fed from the continuous-current generator attached to the motor generator, as described above, with connections, as shown in fig. 101 (*see page* 193).

SAFETY ARRANGEMENTS.—The retarding apparatus, for the purpose of slowing up the winding gear as it approaches the pit mouth, corresponds to cutting off steam on an ordinary winding engine. This is composed briefly of the following (fig 105):—

A horizontal shaft, driven directly by means of bevel gearing from the main shaft of the winding engine. The motion

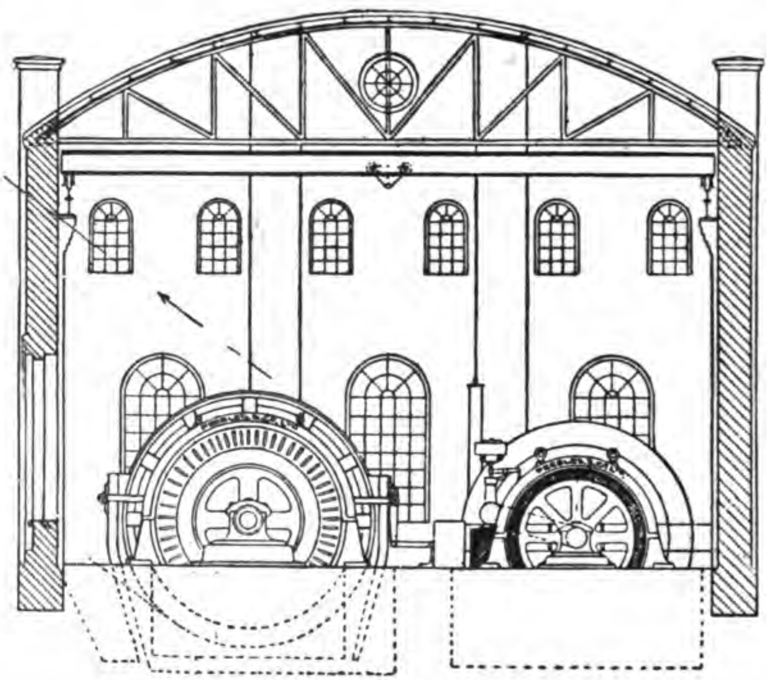


FIG. 104.

in this shaft is transmitted to two parallel shafts placed directly under the bedplate of the machine, fitted with right and left-handed worms and travelling nuts or cursors.

On the pivot of the controller lever are two sectors; the working is as follows:—

When the wind is approaching its end, and the machine has to be slowed down, travelling nut No. 1 has just come into

contact with the No. 1 disc on lever pivot. By its pressure on the same it causes the lever to come gradually back to the position corresponding to the minimum speed attainable, and, as explained above, this operation, under the recuperating principle, brings about an instantaneous and efficient brakage, the energy being thrown back into the line.

By putting the lever on the last notch the retarding apparatus is put out of action, and the cages come to the surface.

The voltage of the last notch is only a few volts, but it is sufficient to enable the attendant to do the last operations, and, when these are finished, push back his lever to zero, thereby commutating the current in the field magnets of the generator.

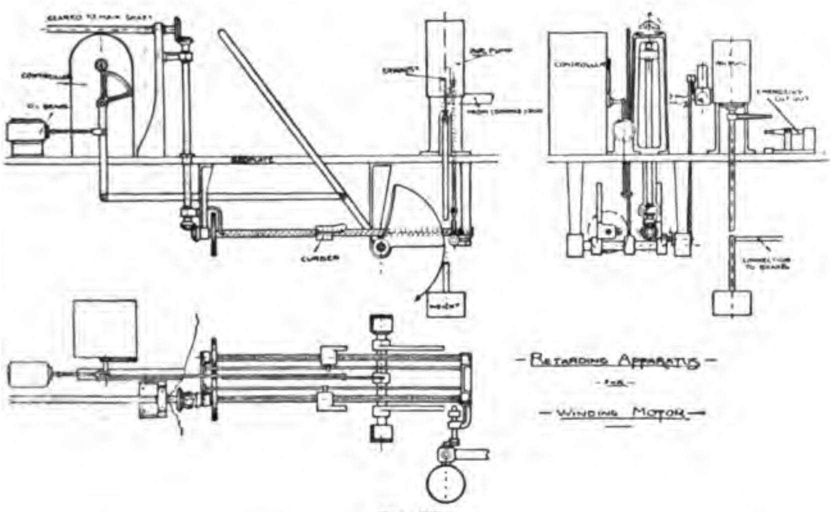


Fig. 105.

If, however, through neglect, he should allow the cage to get up into the pit gearing, one of the travelling screws then presses on another detent opening at the same time the escape valve of the compressed-air piston holding up the emergency brake. This falls down, and in doing so opens the main current, thus stopping the machine.

Brakes.—The brakes, as designed, are two in number. The ordinary working brake, which is identically the same as that used with ordinary steam winding engines, the only difference being that compressed air, produced by an electric compressor, is used instead of steam.

Emergency Brake.—The emergency brake, which consists of a stop brake, operating in the following manner:—An air cylinder with a piston holds up the weight, bringing the brake into action; the section of the cylinder is calculated in such a way that the weight is only completely lifted when the pressure of the air is sufficient to ensure the proper acting of the working brake. The cylinder is provided with a three-way cock, which allows it to be placed in communication with the atmosphere or the reservoir containing the compressed air. This cock can neither be opened by hand nor by the retarding apparatus, as already described, and the falling of the emergency brake causes the current to be immediately cut off.

Automatic Action.—(*a*) It is therefore absolutely unnecessary for the attendant to pay any attention to slowing down his machine; the apparatus does it for him, and also stops it should he be unable to do so. This is a most particular performance, which alone ought to render the use of electric winding engines almost a necessity.

(*b*) Moreover, the attendant cannot start too suddenly, as the travelling nut takes a certain time to get back outside the radius of action of the levers, and full speed cannot be attained before this is done.

(*c*) The maximum speed can never be exceeded; a special speed controller is therefore useless.

(*d*) The sudden stoppage of electric energy from the main does not jeopardise in any way the good working of the gear, as the kinetic energy contained in flywheel is more than sufficient to complete several hauls.

Flywheel Effect should Current be Cut Off.—Should for any reason the supply fail, owing to the large amount of kinetic energy contained in the flywheel several complete winds can be made without any power at all coming from the power station.

It will thus be seen that retarding, braking, and cutting off current are all absolutely automatic and economical in their action, and no damage can be done to the gear through carelessness of attendant.

ELECTRICITY FOR HAULAGE AND PUMPING.

Up to the present the most general application of electrical energy in British collieries has been for purposes of hauling

and pumping. Both are operations which of necessity frequently require power to be conveyed to distant places in the mine far removed from the source of power on the surface.

Hauling and pumping appliances are dealt with elsewhere; in this chapter it is merely the writer's intention to give a few examples of the applications of electrical energy for these operations, with some observations on the subject generally.

So far as haulage is concerned, whatever system be adopted—direct haulage, main and tail, or endless rope,—the speed of the rope, wheel, or drum is slow relatively to the electric motor; consequently some system of speed reduction is necessary to reduce the motor speed of 400, 500, 700, or even 1000 revolutions per minute to one of 10 or 20 for the haulage rope. This may be effected in either by a train of gears with or without a belt or rope drive from the motor, or by worm gearing.

The latter (worm gear), for small hauling arrangements, has been used with considerable success, the efficiency of a well-designed worm gear, running in an oil bath, being well over 90 per cent. It has the advantages of smooth and noiseless running, and it is quite impossible for the load to overpower the motor and run back should the current supply, from any cause, fail.

For larger hauling arrangements the motor may either be geared directly on to the first motion—that is, with a pinion on the armature shaft, or a belt or rope drive may be adopted. In the former case the very greatest care must be given to the selection and make of the gears, the pinion on the motor, and the wheel into which it gears must be machine cut and perfectly smooth running secured. Raw hide pinions on the motor shaft, gearing into machine-cut wheels, are very largely used, and when the gears are carefully made this arrangement gives very satisfactory results. The flexible drive from the motor, either with belt or ropes and grooved pulleys, undoubtedly obviates the difficulty of the vibration being transmitted to the armature.

In all cases of machinery driven by electric motors, the gearing should be of the most perfect make; machine-cut teeth for the higher speeds, machine-moulded double-helical gearing for the heavier and more slowly-moving wheels.

With good and carefully-proportioned gearing an efficiency of over 90 per cent is possible.

In electrically-operated haulage gears, we most strongly advocate, as a general thing, the employment of a friction clutch. The advantages of a good type of clutch are numerous, perhaps the most important being that the haulage rope can be almost instantaneously stopped, should occasion arise, by throwing out the clutch. As a simple illustration, take the case of a haulage gear in which the rope wheel or drum is revolving 10 or 15 times per minute, whilst the motor has a speed of 400 or 500 revolutions, or even more. Suppose, whilst the haulage is in action, something happens in the haulage plane demanding the instant stopping of the rope to avoid a serious accident, or to prevent greater damage than may already have occurred. The slowly-revolving rope wheel may be thrown out of gear, the brake applied, and the wagons brought to a stand almost instantly. In the absence of a clutch the motor switch would be opened, and the gear would continue to move until the rapidly-revolving rotor, or armature of the motor, had been brought to rest. During the interval considerable damage may have been done, or possibly a life lost.

A few examples of electrically-operated haulage gears are illustrated in the chapter on haulage.

PUMPING.

Generally speaking, the same necessity for speed reduction obtains when the electric motor is applied for pumping.

The great majority of pumps employed for colliery purposes have a reciprocating motion, and not only has gearing to be provided to reduce the speed, but the crank and connecting rod arrangement has to be applied to convert the rotary motion of the motor into the reciprocating motion of the pump.

The arrangement which would appear to be most popular, in British colliery practice, consists of a set of three single or double-acting pumps with a three-throw crank, the cranks being set at equal angles with each other of 120 degrees. This gives a fairly uniform load, and the whole arrangement is simple and not likely to get out of order. As in the case of the haulage, the motor may be directly geared, or the belt or rope drive may be adopted.

Continental and American practice is somewhat ahead of British practice in the application of electrical power for pumping; improvements have been effected in the pumps which render them better adapted for electrical driving, and dispense with much or all of the gearing. Details of the pumps themselves will be given in the section devoted to pumping, where we introduce illustrations of several types of electrically-operated pumping arrangements.

There is one point which might be mentioned with regard to electrically-driven pumps—those operated by means of polyphase motors; they are less liable to be "drowned out," or, at least, need not necessarily be stopped although actually submerged in water. It is not suggested, of course, as a good arrangement that electrical pumps should be worked overhead in water; it is merely mentioned as an interesting fact that a polyphase motor and pump *could* continue to work even under water.

VENTILATION.

It will scarcely be necessary to point out the convenience with which electrical energy may be utilised for working small auxiliary fans to assist in the ventilation of extensive workings. The motor is coupled directly to the fan, and forms a compact and efficient arrangement.

One great feature of electrical power at a colliery is the ease with which power can be taken to any part of the mine or distributed upon the surface. At an average colliery one finds a dozen or more of small or medium engines, all more or less—generally less—efficient, and all doing their little to swell the colliery fuel consumption. We have an engine, or perhaps more than one, in the workshops and sawmill, another for the screens and picking belts, and for other purposes. The fan engine is usually a larger affair, but there is no reason why, with electrical power at the colliery, all these engines should not be dispensed with, and the power applied electrically. Instead of several engines, mostly wasteful, we should have the highly-efficient generating engine. It is important, however, that the load in the generating engine be kept as uniform as possible, and in this sense there is an advantage in driving the fan electrically. The load is constant, and, as a rule, fairly large, which would help to equalise the load on the generators.

The mechanical ventilator is peculiarly adapted for electrical driving. Its simple rotary motion, at a fairly high speed, makes it possible to couple the motor directly, thus dispensing with belts or ropes, and saving the expense of costly engines, large engine house, and massive foundations.

THE DANGERS TO BE GUARDED AGAINST.

We cannot leave this section of the work without reference to the precautions which must be taken to prevent accidents from the use of electricity in mines.

No one will deny that there are dangers attending the use of electricity, but these need not be any greater than those attending the use of steam, and, as a matter of fact, are not any greater; they are different in character, and perhaps not so familiar as those in connection with the generation and application of steam power, which we have learnt to recognise and control.

With regard to electrical dangers, it is largely a question of becoming familiar with the different character of the dangerous element, exercising reasonable care, and adopting the needful precautions.

A steam boiler, working, say, at 150 pounds per square inch, is by no means a harmless contrivance. It represents potential energy capable of working frightful destruction, but we do not hesitate to employ such arrangements. We know where the dangers lie; we know what we are to do and what to avoid. We demand excellence of material and workmanship; we provide suitable safety valves and other appliances; strict care is exercised in working, and periodical cleaning and inspection carried out.

With electrical appliances we must exercise similar vigilance and care. Electrical shocks may cause serious and fatal injury; we must take such precautions as will make it well-nigh impossible for persons to receive shocks. Excess of current in any conductor may cause fire; we must make provision for obviating the possibility of excessive current. Defects in cables and connections may cause sparks and flame; we must avoid these defects, and by systematic inspection make it impossible for defects, which may develop from time to time, to remain undetected. Defective or unsuitable appliances may cause

sparking; we must avoid such appliances, and, most of all, having provided suitable appliances in the first instance, we must not allow them through neglect to become defective or faulty. None of these things are difficult; all are perfectly reasonable and practicable.

One might be allowed to urge, too, the immense importance of an intelligent knowledge of the leading principles of electricity on the part of all those whose duty in the mine involves the handling or control of electrical appliances. The men so employed should be carefully selected and as carefully trained, and we have no hesitation in suggesting simple courses of lectures on electrical principles for the especial benefit of these men—lectures which might be arranged and provided for by the proprietors of the particular concern where electrical energy is employed. Such an arrangement would prove beneficial to all concerned—the employer and employee.

The writer is personally acquainted with at least two fatal accidents arising from electricity in collieries, both of which were almost entirely due to the absence of this easily-acquired knowledge of general principles.

It is not possible to find words strong enough to condemn the practice which for a long time has obtained here and there, in colliery engineering, of adopting "make-shifts." Under any circumstances this idea of colliery engineering is sufficiently pitiable; but in connection with electrical colliery engineering it ought not, for a moment, to be tolerated. Only the most perfect and the best appliances should be employed—make-shifts never.

The writer has seen one electrical installation at a colliery where the only means of disconnecting a circuit underground was by *opening the fuse box and taking out the fuses*, and has heard of another in which the starting switch for a motor consisted of a tub of water, into which the motor attendant had to dip an iron plate attached to a piece of flexible cable. Collieries where these things are permitted are not places for the application of electrical energy—clockwork motive power would be far safer and better suited for people with such ideas.

ELECTRICAL UNITS AND CALCULATIONS.

It has been the writer's practice, in connection with his

lectures to practical mining men, to endeavour to explain the more commonly-used electrical terms and units by a comparison with the more familiar subject of mine ventilation; and although, no doubt, most of our readers will by this time have an intelligent idea as to the significance of such terms as volt, ampere, ohm, watt, kilowatt, megohm, etc., the desire is to make this work useful and intelligible to those who still have some little difficulty in grasping the import of terms which are comparatively strange to them.

Various authors on the subject of electricity have likened the generation and flow of an electric current to water flowing under pressure through a pipe, but the writer knows of no more perfect illustration than that afforded by mine ventilation, and in this sense the mining student is particularly fortunate.

In both cases we are dealing with the generation and flow of a current through suitable conductors, and the control and distribution of that current.

In each case boilers and engines represent, in the majority of cases, the initial stages in the operations, and the fan and generator are alike in one sense—both are simple rotating machines.

For the transmission of the electrical and the air current conductors are provided, at least two, the lead and the return cable, the intake and return airway. The laws which control the electrical current in the conductors are not unlike those we are familiar with in connection with the flow of air in the mine. For instance, the resistance of a conductor is exactly proportionate to its length; the same is true of the airway in the mine. The resistance of a mine airway varies inversely as its sectional area; the statement is also applicable to the electrical conductor.

The ventilating pressure, under the influence of which the air current is made to flow, is measured in inches of water gauge; the corresponding unit of pressure in electricity is called the *volt*. In place of the expression "cubic feet per minute," by which the air current is measured, we have the *ampere* in electricity. The co-efficient of friction, airway resistance, in mine ventilation finds its equivalent in the *ohm*, the unit of electrical resistance. In mine ventilation we multiply the air current in cubic feet per minute by the ventilating pressure,

and we get the power absorbed in foot pounds per minute. Similarly the electrical current in amperes multiplied by the pressure in volts gives the power in *watts*, the unit of electrical energy.

Foot pounds per minute divided by 33,000, and watts divided by 746, both give the familiar unit the horse power; in other words, 746 watts equal one horse power.

In order to give some practicable idea as to the relative proportions of the electrical units, it may be explained that a single copper wire, of No. 17 standard wire gauge, 100 yards long, offers a resistance of practically one ohm, and a difference of pressure of one volt between the two extremities of this wire would cause a current of one ampere to flow.

A wire of this size, No. 17 standard wire gauge, measures ·056 of an inch in diameter.

The relationship between these several electrical units is thus easily established. Divide the current pressure in volts by the resistance in ohms, and the result is the current in amperes.

$$\frac{\text{Volts}}{\text{Ohms}} = \text{amperes.}$$

Thus, with a pressure of 500 volts and a resistance of 50 ohms, the current flowing would be $\frac{500}{50} = 10$ amperes.

The watt, it may be explained, is the power represented by a current of one ampere at a pressure of one volt; the power in the above case, therefore, would be $500 \times 10 = 5000$ watts.

Similarly, if we have to provide for a current of so many amperes with a given resistance in ohms, we multiply the two together for the requisite pressure in volts, thus, 10 amperes × 50 ohms = 500 volts. And again, if we are told what current flows with a given pressure, we may calculate the resistance in ohms thus:—

$\frac{\text{Volts}}{\text{Amperes}} = \text{ohms}$, or applying the same figures $\frac{500}{10} = 50$ ohms.

It must be explained, however, that the rules above given in this simple application refer to continuous current only. With alternating current the rules become a little more complicated.

We have already seen that the watt = amperes × volts, and since amperes × ohms = volts it follows that we can also calculate

the power in watts, if the current and the resistance alone are given. Thus, watts = amperes × volts, and volts = amperes × ohms, therefore watts = amperes × amperes × ohms, or watts = amperes squared × ohms.

THE LOSSES IN ELECTRICAL TRANSMISSION.

In making calculations as to the power required for various purposes, and the leading dimensions of the plant, it is necessary to have some information with regard to the losses in the various stages of the power transmission, and the efficiency of the process.

Commencing, then, with the steam engine, it may safely be claimed that the types of engine employed for the purpose of driving electrical generators will give an efficiency as high as 93 per cent, or even 94 per cent—that is, between the indicated horse power and the brake horse power.

The electrical generator is perhaps the most perfect means of converting one form of energy into another with regard to the losses incurred, and 90 per cent efficiency is quite a moderate figure for a well-designed dynamo. Indeed, many makers are quite prepared to guarantee a still higher efficiency; still, from our point of view, we prefer to err on the right side if at all, and will set down the combined efficiency of the engine and generator at 75 per cent; that is to say, 100 horse power developed in the steam cylinders will give 75 electrical horse power at the generator terminals.

We come next to the line losses—the losses due to the resistance of the conductors. The amount of this depends upon a number of circumstances, and the question will be considered more in detail later. For the moment we may assume a loss of about 10 per cent for a distance of, say, a mile between the generator and motor, or 90 per cent efficiency. $75 \times 90 \div 100 = 67{\cdot}5$ electrical horse power delivered to the motor for 100 horse power developed in the steam cylinders.

Finally we have the efficiency of the motor. It will not be unreasonable to take 90 per cent as an average with good motors; $67{\cdot}5 \times 90 \div 100 = 60{\cdot}75$, say 60 per cent; that is to say, 100 indicated horse power developed in the steam cylinders would give about 60 brake horse power from the motor. Of course, each case would have to be taken on its own merits; but

it would be fair to say that, with reasonably good appliances, for a distance of about one mile between the generator and motor, the overall efficiency would be not less than 50 to 60 per cent.

As an example, take the case of a three-throw pump to deliver 200 gallons per minute to a height of, say, 660 feet. $200 \times 10 = 2000$ pounds of water per minute, and multiplied by $660 = 1,320,000$ foot pounds per minute in water to be raised = 40 horse power. A practical allowance for the efficiency of the pump and gearing, and the friction of the water in the pipes, will be about one-half of this, or 20 horse power, making a total of 60 horse power as the power required from the motor.

On the figures given above this would mean the provision of 100 indicated horse power in the steam engine for the pumping, and assuming a current pressure of 500 volts at the motor terminals and a motor efficiency of 90 per cent, this would mean—

$$\frac{60 \times 100 \times 746}{90 \times 500} = 99{\cdot}46, \text{ say } 100 \text{ amperes.}$$

By observing the indications of the ampere meter and volt meter connected with a continuous-current motor, multiplying them together, and dividing by 746, we get the electrical horse power of the motor.

In dealing with polyphase currents the calculations one may be called upon to make are of a somewhat more difficult character to explain. The same units are employed, but as a simple example it might be pointed out that volts multiplied by amperes and divided by 746 would not give the power of a three-phase haulage or pumping motor. Similarly, something more than this simple calculation is necessary to show the power given out by a three-phase generator supplying power for these operations.

In the first place, we have to remember that we have what might be described as a combination of three alternating currents whose alternations overlap but do not coincide—we have a certain voltage and current in each of the three conductors of the three-phase system, but the voltage, in each case, is rapidly alternating from a positive maximum to a negative maximum, and the three sets of alternations follow each other at equal intervals, so that no two attain the maximum pressure at the same moment. Instead of taking, then, the voltage and cur-

rent in each phase and multiplying by 3 for the total power, we take the phase voltage, multiply by the phase current and by 1·73, which is the square root of 3. We have further to multiply by what is called the power factor. An example will make this clear:—

Required the electrical horse power of a three-phase generator giving, say, 290 amperes at a pressure of 440 volts, assuming a power factor of ·9. $440 \times 290 \times 1{\cdot}73 \times {\cdot}9 = 198{,}673{\cdot}2$ watts, or, in round numbers, 200 kilowatts, that is 200,000 watts. Dividing by 746 we get the electrical horse power, equals, say, 266.

The electrical energy required by a motor is arrived at by a similar calculation. For example, a three-phase motor supplied with current at 440 volts, taking 30 amperes, assuming a power factor of ·8, consumes $440 \times 30 \times 1{\cdot}73 \times {\cdot}8 = 18{,}268$ watts, say 24½ electrical horse power.

POWER FACTOR.

It is necessary at this point to explain the meaning of the term "power factor" used in the above calculations. In the alternating current the pressure rapidly alternates from a positive maximum to a negative maximum, and if the current is supplied to motors, or other inductive load, the maximum current lags behind the maximum pressure. This does not imply any actual loss or lower efficiency; it affects the calculations and makes it necessary to make provision in the conductors for a slightly larger current. It may be illustrated by the example afforded by the case of two men who have made an appointment to meet at a certain time to transact certain business. One of the two is at the appointed place exactly at the time arranged, and is compelled to leave ten minutes later; the other is two minutes late, so that they can only spend eight minutes together. The power factor is ·8; had they both arrived at the proper time the power factor would have been 1·0.

SWITCHBOARDS AND FITTINGS.

Quite as important as the generators and the motors, and requiring the most careful attention both during erection and afterwards, are the distributing arrangements in the electrical installation. Only too long has the idea prevailed in some quarters that the cables were matters of secondary importance;

that their fixing in the shafts and disposal in the roadways might be entrusted to any colliery mechanic. No greater fallacy could exist, and no risks should be taken in connection with these arrangements, which must be carried out by an expert aided by men who have some knowledge of matters electrical.

In the power house the current from the generator is carried to the bus bars behind the switchboard, but between the generator terminals and the bus bar connections there must be provided on *each* pole a switch and fuse, or an automatic circuit breaker. This latter is a contrivance which breaks the circuit in the event of either an excessive current or a reversal of current.

The switchboard consists of panels of slate or marble suitably mounted in a framework of angle iron, and drilled with holes and openings to accommodate the various connections. The connections should be so arranged that no "live" metal appears on the front of the board. Ample space should be provided behind the switchboard to give free access to the various connections. An excellent plan is that in which the switchboard is built into the wall, with the back forming the wall of a separate room specially set apart for the purpose of giving access to the back of the board. This room should be well lighted, dry, and, so far as possible, built of incombustible materials.

Separate panels are provided for the generator connections, and the circuit or distribution connections. The instruments required are the following, namely: On the generator panel, the main switch, which must simultaneously break the circuit on each pole; for a single generator, continuous current, this will be a double-pole switch; for a three-phase alternator, a triple switch. On each pole there must also be a fuse, or, better still, an automatic circuit breaker, the object of which is to open the circuit in the event of a predetermined current being exceeded; an ampere meter to indicate the current output of the generator, and a volt meter to show the pressure. The automatic circuit breaker, which operates when a certain current is exceeded, is frequently arranged to act also in the event of the current being reversed. A shunt regulator is also provided, with resistances, to enable the voltage of the dynamo to be regulated within certain limits. An earth detector, for

indicating leakage of current, must always form part of the switchboard equipment. (*See fig.* 106.) If both lamps are equally bright there is no leakage. If lamp B is brighter than A it indicates a leak on the + main, and *vice versa*.

The distribution panel will provide a double-pole switch, with fuses or circuit breakers, and an ampere meter for each circuit.

For alternating current—say three-phase—the details are somewhat similar; three ampere meters are provided on the generator panel.

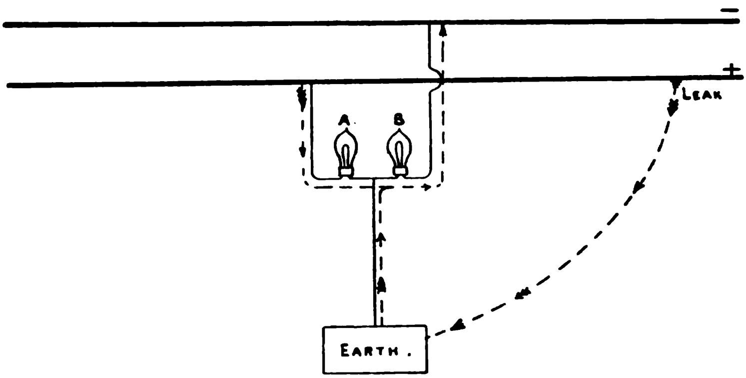


FIG. 106.
DIAGRAM TO ILLUSTRATE AN "EARTH" DETECTOR.

The continuous-current motor switchboard is a smaller and somewhat less complicated edition of what has already been described—a slate or marble panel with a double-pole switch, an ampere meter, and an overload, and no volt circuit breaker. Sometimes a shunt regulator is provided for varying the speed of the motor.

The starting of a continuous-current motor is an operation which must be carried out with care. As in most other operations, there is a right and a wrong way. To attempt to start the motor by simply closing the main switch would be to court disaster. Indeed, the arrangements are so made that the closing of the main switch is only the preliminary operation. Until the motor speeds up the current must only be allowed to flow through the armature at reduced pressure, for which purpose a starter is employed. In this appliance the current has first to pass through a considerable resistance, which is gradually cut out

as the motor speeds up by *slowly* moving the handle or lever. Even these appliances are sometimes wrongly used, resulting in damage to the appliances, and this fact has led to the production of what its inventor terms a "fool-proof" motor starter.

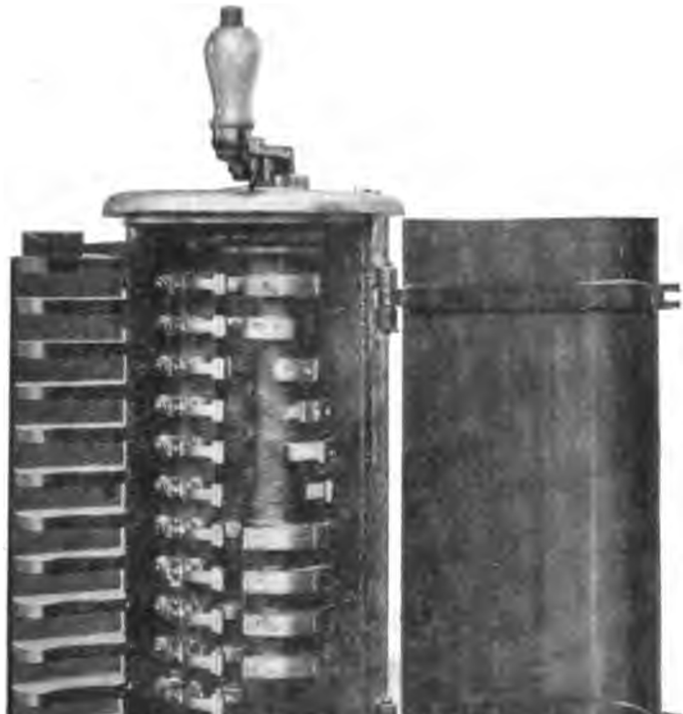


FIG. 107.
A BRITISH THOMPSON-HOUSTON TRAMWAY-TYPE CONTROLLER.

Motor starters are of three general types—the liquid type, the switch type, with metallic resistances, and the tramway type, which is more correctly described as a "controller."

The former is a cheap and, in many cases, no doubt, an

effective substitute for a more costly appliance. In this arrangement, the decreasing resistance is effected by gradually lowering an iron plate into a vessel of water. As the area of the plate immersed increases the resistance decreases and the current increases. Finally a metallic contact is made, and the liquid resistance cut out. These appliances are no doubt all right when properly applied and used, but the writer has seen cases of colliery motors with liquid starters where the liquid was only too conspicuous by its absence. With a good type of "fool-proof" motor starter little can go wrong.

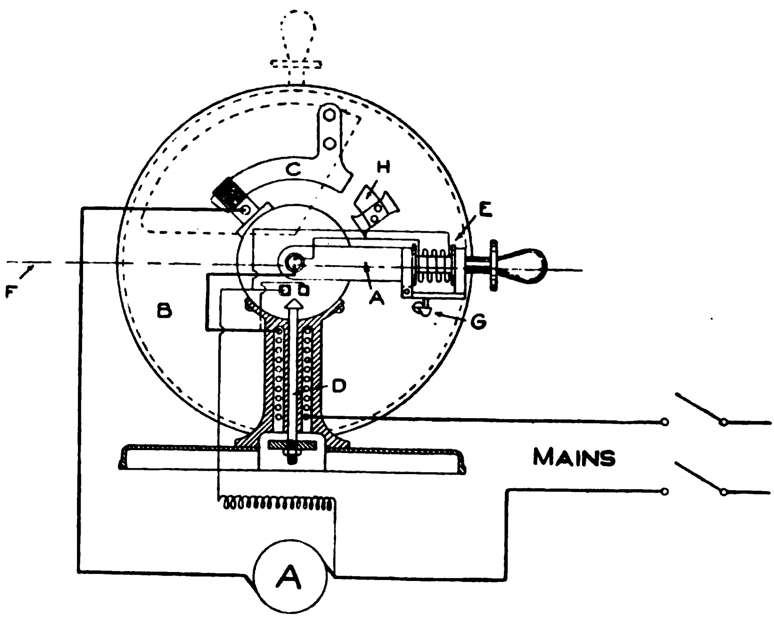


FIG. 108.

WOOLLISCROFT'S PATENT ENCLOSED LIQUID STARTING SWITCH, WITH MAXIMUM AND MINIMUM RELEASE. F INDICATES THE LEVEL OF THE LIQUID (Made by BERTRAM THOMAS, of Hulme, Manchester).

The second type is for starting only, and the lever is moved slowly across the studs to the extent of its travel, where it is held in position so long as the current flows. In large motors this lever is often actuated by a slow motion which prevents the current being turned through the motor too quickly. These are usually arranged to fly back to the off

position when the current supply is either intentionally or from any other cause interrupted.

If, however, the motor has to be worked at a variable speed and reversed, the tramway type is most suited. The general idea is illustrated in fig. 107 (*see page* 211). No useful purpose would be served by attempting to explain its construction in detail; it will suffice to say that it enables the motor to be started, stopped, reversed, and made to go quicker or slower in either direction.

The actual reversal of motion of the motor is effected by reversing the current in the magnet coils.

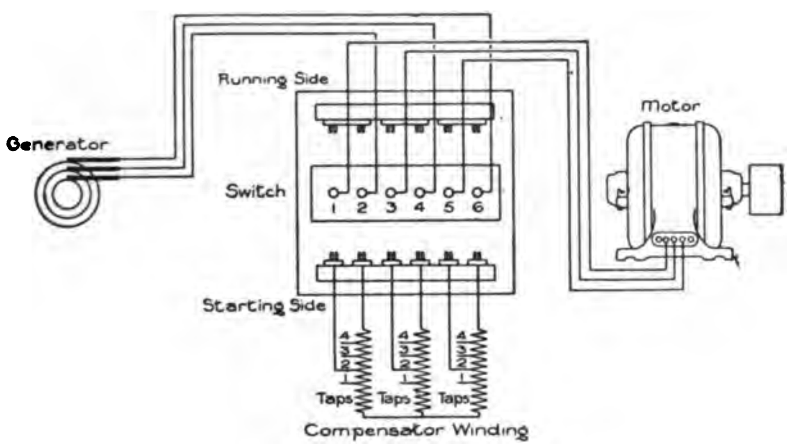


FIG. 109.

DIAGRAM SHOWING THE CONNECTIONS FOR THE AUTO-TRANSFORMER STARTING SWITCH FOR A THREE-PHASE SQUIRREL-CAGE MOTOR (BRITISH THOMPSON-HOUSTON).

The starting switch for a short-circuited or squirrel-cage three-phase motor is a different affair. For this purpose an auto-transformer is used, the current being first delivered to the stator windings at a lower voltage; when the motor has speeded up the full voltage current is switched on. The starting switch has three positions: the middle position opens the circuit, the handle is moved in one direction to close the low-tension switch, and when the motor has attained its proper speed the handle is quickly thrown over to the other side to close the direct circuit, simultaneously cutting out the transformer arrangement. (*See fig.* 109.)

The reversal of a three-phase motor is effected by changing any two of the three connections; this, of course, is properly provided for by a specially-contrived switch.

In the slip-ring type of three-phase motor the starting is effected by means of an external resistance and a starting switch. The resistance is connected in series, by means of the slip rings, with the rotor winding, and in starting the motor the resistance is gradually cut out as the motor speeds up, just as in starting a continuous-current motor; the rotor windings are finally short-circuited. This starting switch and resistance, it must be understood, does not deal with the current from the mains, only with the low-pressure current induced in the rotor windings. (*See fig.* 110.)

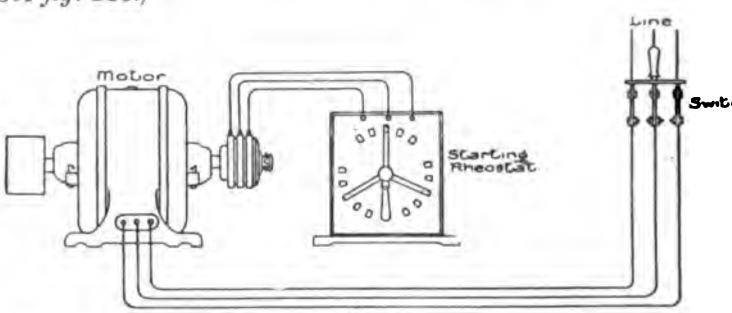


FIG. 110.
DIAGRAM SHOWING THE CONNECTIONS AND STARTING RESISTANCE FOR THE SLIP-RING MOTOR (BRITISH THOMPSON-HOUSTON).

All switches, circuit breakers, and fuses for use underground should be enclosed in gas-tight boxes, unless used in places where there is absolutely no possibility of inflammable gas being present, and all the metal parts, covers, etc., not intended to carry current should be properly earthed.

CONDUCTORS AND CABLES.

The cables must be of ample sectional area and perfectly insulated. Cheap, so called, cables generally prove to be the most expensive of electrical appliances, resulting, it may be, not merely in destruction of property, but loss of life.

CURRENT DENSITY IN CABLES.

The actual conductor is pure copper wire, which, next to silver, is the most perfect electrical conductor; that is, it offers

a lower resistance than other metals. The writer has been informed that experiments are in progress with the object of discovering a process of making steel wire which shall have the conductivity of copper, whilst retaining the valuable properties of steel; such a discovery would well-nigh revolutionise electrical engineering.

There is, however, a limit to the current which a given conductor can safely carry. Just as an air current, travelling at a high velocity through an airway, encounters resistance, which means that some of the work expended in producing ventilation is converted into heat, so also the electrical current, flowing through a conductor, encounters resistance, in overcoming which some of the electrical energy is converted into heat. Now, if this heat is excessive, not only does it mean that the loss in transmission is excessive, it also means that the cable itself becomes unduly heated, and this may seriously affect the insulation.

In practice, therefore, the current density is limited to 1000 amperes per square inch of the sectional area of the copper. For example, a conductor with a sectional area of one-tenth of a square inch should not carry more than 100 amperes. This current density of 1000 amperes per square inch, however, is only suitable for cables carrying not much more than 100 amperes, because as the cables become larger there is greater difficulty in dissipating the heat.

For a current of 700 amperes the current density should not exceed 700 amperes per square inch, which would mean a conductor having a sectional area of one square inch. The current density permissible will gradually increase as the current decreases. Thus, for 400 amperes, the density would be 800 amperes per square inch, equals conductor area of ·5 of a square inch.

The resistance of a conductor gives rise to a certain loss, called the "drop"—that is, drop of current pressure or voltage,—which has to be provided for. This drop is easily calculated in continuous-current systems by simply multiplying the current in amperes by the resistance of the conductor in ohms. It is independent of the voltage, and therefore the higher the voltage the less is the percentage drop in any given case. To transmit the same amount of energy at a higher voltage, a lesser current

in amperes is needed, and therefore a smaller cable will suffice. The drop is proportional to the length, and for this reason high voltage is to be preferred for long-distance transmission. To calculate the actual loss of energy due to voltage drop, the drop in volts multiplied by the current in amperes equals the loss in watts. Or the same result can be calculated by the amperes squared and multiplied by the total ohms.

For example, a cable one mile long, consisting of seven wires of No. 17 wire gauge, has a resistance of about 2·5 ohms per mile, and at a current density of 1000 amperes per square inch will carry 17 amperes. The voltage drop would be $17 \times 2{\cdot}5 = 42{\cdot}5$ volts, and the loss in watts would be $17 \times 42{\cdot}5 = 722{\cdot}5$ watts. Or, by the other method, $C^2R = 17^2 \times 2{\cdot}5 = 722{\cdot}5$ watts, as before.

Suppose these figures related to a 500-volt circuit, where the 500 volts represented the pressure at the generator. The loss due to drop in the cable amounts to nearly 9 per cent. If the pressure at the generator terminals had been 5000, then the current to be transmitted for the same watts—8500—would be 1·7 amperes instead of 17 amperes, and the drop, assuming the same cable were used, would be $1{\cdot}7 \times 2{\cdot}5 = 4{\cdot}25$ volts, or a loss in watts of $1{\cdot}7 \times 4{\cdot}25 = 7{\cdot}225$ watts, as against 722·5. The percentage loss of energy in this case would be less than ·09.

Of course, in practice the same cable would not be used, the advantage of the higher voltage being that a much smaller and less costly wire would carry the current with the same or even less loss. A single wire of No. 18 standard wire gauge will carry the current last arrived at, 1·7 amperes; and such a wire offers a resistance of 23·38 ohms per mile. $1{\cdot}7 \times 23{\cdot}38 = 39{\cdot}746$ volts drop, say 40. The loss in watts would be $1{\cdot}7 \times 40 = 68$ watts, or ·8 per cent loss.

TO CALCULATE THE SIZE OF A CABLE.

The calculations relating to electrical conductors and cables become rather complicated when gone into deeply. For the purposes of this book such calculations are better omitted, and only simple rules employed such as are likely to meet the requirements of most of our readers. The size of a cable, as already pointed out, depends upon the current it has to carry and the current density permissible.

In practice, however, there is another point to be taken into consideration—the relationship between the cost of the cable and the loss of energy due to voltage drop. We can reduce the latter to a minimum by the employment of large and costly cables, or we can reduce the cost of the cables by accepting a certain loss of energy due to voltage drop. Generally the voltage drop permissible is determined. The greater number of colliery installations with continuous current are nominally 500-volt systems, but the generator is usually over-compounded to give 550 volts at full load, so as to provide for voltage drop, still leaving the effective voltage at the motor terminals 500, a drop of 50 volts.

The following rule enables the sectional area of the conductor to be calculated in square inches for a given current, a given distance, and a stipulated voltage drop:—Multiply the current in amperes by the total length of conductor in yards—lead and return,—and divide by the voltage drop multiplied by 40,000.

Example: What is the sectional area of a conductor to carry 20 amperes, the distance between the generator and motor being 1150 yards and the voltage drop permissible 50?

$$\frac{20 \times 2{,}300}{50 \times 40{,}000} = \cdot 023 \text{ square inches.}$$

The area of a conductor with seven wires of No. 16 standard wire gauge is ·02227.

Still more complicated are the calculations relating to conductors for three-phase alternating current. A simple rule, giving approximately accurate results and sufficient for the purposes of this work, is the following:—Make the calculation as if for continuous current, and having found the area of the copper in the conductor, divide by two for the area of each of the three conductors for three-phase transmission.

For example, in the case above given the sectional area of the conductor works out to ·023 square inches, and this divided by 2 = ·0115 square inches.

The total area of copper, lead, and return in the conductor for continuous current is ·023 + ·023 = ·046, and the total area of the three conductors for three-phase current is ·0115 + ·0115 + ·0115, or ·0345. It will be observed that there is, as a matter of fact, only 75 per cent as much copper used for the three-phase as for the continuous, although there are three conductors as against two.

The nearest size of conductor to the calculated result, ·0115, is one composed of seven wires of No. 18 standard wire gauge or 19 wires of No. 22 standard wire gauge.

INSULATION OF CABLES.

Whilst the size or sectional area of a conductor is determined entirely by the current, the insulation is entirely determined by the voltage. The higher the voltage the thicker must be the insulation, and the greater must be the resistance offered by that insulation. No "earthed" returns are permissible in colliery installations. On the other hand, all metal work—frames of motors, armouring and metal-casing of cables, switch-boxes, junction boxes, transformer frames—which is not intentionally live *should* be earthed. In brief, whilst all metal which carries current pressure must be perfectly insulated, all metal forming part of the electrical arrangements, but not intended to carry current, must be earthed—the idea being to safeguard so far as possible, from accidental shocks. Suppose, for example, a cable is carried through a metal pipe or tube, the latter not being earthed, and suppose that accidentally contact is made somewhere between the live conductor and the pipe. A man standing on a damp place, and touching the pipe with his hand, might receive a bad shock; but if the pipe were earthed, the current would take the path of least resistance, and the man would feel little or no shock. A serious leakage of this character would indeed be immediately detected in the power house.

Electrical conductors or cables for use in mines have to be protected electrically—that is, insulated—to prevent leakage and shock; and also mechanically protected to prevent damage to the insulation. The electrical protection or insulation is provided by enclosing the copper conductor in a continuous and sufficiently thick sheathing of suitable material; vulcanised bitumen, rubber, specially prepared paper, and other preparations, are used for this purpose.

The advice of a reliable cable-maker should always be obtained with regard to the kind of insulation best suited for any particular case. A wet mine, for instance, requires a special insulation.

The mechanical protection, rendered necessary when the cable is exposed to possible injury from falls of roof, etc., takes

the form of armouring, and this consists either of steel tapes coiled in opposite directions or, better still, two coils of galvanised steel wires. Opinions differ as to the desirability of the armouring of cables for mining purposes. The balance of expert opinion which the writer has been able to secure seems to be *against* armouring, and it would appear that cables of best quality, thoroughly insulated and carefully arranged in the mine roadways, are not only less costly but safer than armoured cables installed in the manner only too frequently met with in colliery practice, in which the electrical continuity of the armouring is interrupted in places, and either imperfectly earthed or not earthed at all.

In a fatal accident which came under the writer's personal observation, the cables used were armoured, the voltage was *below the limit of low pressure as laid down in the new rules*—namely, 240 volts. A man made accidental contact with his bare back on these armoured cables, and was almost immediately killed. It should be made clear, however, that this was one of the cases which merely go to show that armoured cables, improperly used, are dangerous.

There can, perhaps, be no safer or better system underground than armoured cables, provided that the electrical continuity of the armouring is ensured throughout the system, and that it is properly earthed.

In the mine roadways the cables should, for preference, be suspended with plenty of slack between the points of suspension on opposite sides of the road. The attachment must be of such a character as to allow the cable to break away easily without taking any strain, in the event of a fall of roof.

Where joints have to be made in cables, the greatest possible care must be exercised; and for this purpose joint boxes must be used. As a rule, soldered connections should be made, and where this cannot be done in a mine the very best form of mechanical clamp must be used. Where shots may be fired it is permissible to make soldered joints.

If the cable is armoured, care must be taken to see that the metallic continuity of the armouring is restored. The reader will observe how this is provided for in the joint boxes illustrated. All armouring, junction boxes, switch boxes, transformer boxes, switchboard frames, motor frames, and bedplates—in fact, *all*

appliances or parts of appliances in connection with electrical arrangements, which do not intentionally carry current should be earthed. The new regulations do not press this point if the pressure does not exceed the limits of low pressure (250 volts), but this is a privilege we ought to be slow to take advantage of. The earthing of these metallic parts means the making of efficient contacts between them and the earth, by means of connecting wires to plates buried in the earth at suitable points. The intention is that if, by any mishap, these metallic parts become live, a person touching them could not receive a serious shock, since a better connection already exists with earth than that made through the person's body. There is, as a matter of fact, no difference of pressure between the earthed metal and the earth.

The varying conditions under which electrical conductors have to be used in mines, conditions for the greater part of a most unfavourable character from an electrical standpoint, require not only that the conductors shall be of the most perfect construction, but also that care and skill shall be bestowed upon the choice of suitable insulating materials.

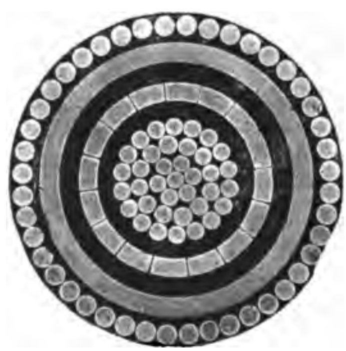


Fig. 111.

A Concentric Cable, Lead Sheathed and Armoured, British Insulated and Helsby Cable Company Limited.

Most of the best-known firms of cable makers have given special attention to the manufacture of cables for colliery use, and much useful information has been placed at our disposal by such well-known makers as the British Insulated and Helsby Cable Company Limited, whose works are situated at Prescot, Lancashire, and Helsby, Cheshire; Messrs. W. T. Glover & Company Limited, of Trafford Park, Manchester; Messrs. The

St. Helens Cable Company Limited, of Warrington; and Callender's Cable and Construction Company Limited, of London, and the Belvedere Works, Kent.

An electrical cable, for mining work, necessarily consists of the conductor and the insulation. The former is invariably copper; for the latter different materials are used. The conductor usually takes the form of copper wires stranded together, sufficient in number and size to give the requisite sectional area. As a rule, the individual wires are not larger

FIG. 112.
A THREE-CORE THREE-PHASE HELSBY CABLE.

than No. 14 standard wire gauge; larger wires would tend to produce an inconveniently stiff cable. For continuous-current work single cables are generally used—that is, a separate cable for the lead and another for the return. Concentric cables are, however, sometimes employed, in which both the lead and return are embodied in the one cable. An example of a concentric cable, made by the Helsby Company, is given in fig. 111. The inner conductor is composed of round copper wires stranded together, the outer conductor, separated from the inner by insulating material, being in this case composed of wires of wedge-shaped section. This cable is served with lead to keep it waterproof, and armoured with steel wire.

Fig. 112 gives a section of a Helsby three-core three-phase

cable. The three conductors are surrounded with insulating material, sheathed with lead and armoured with steel wire. As already explained, in a three-phase cable, if it is necessary to protect the conductors with metallic covering, all three conductors must be contained within one covering. Fig. 113 is a four-core lead-sheathed Helsby cable.

FIG. 113.
A FOUR-CORE HELSBY CABLE.

The Helsby Cable Company furnish the following remarks on the handling and use of cables:—

USE AND ABUSE OF ELECTRIC CABLES.

HANDLING.—Cables should be treated with great care before and while being fixed. Coils of wire or cable should not be trodden upon, nor heavy goods be rolled over or placed on them. Avoid rolling drums of cable against each other, else the flange of one drum may bruise the cable on another drum. Taking wire off a coil sideways puts a twist or kink in the wire for each convolution straightened. To prevent this, roll the coil along the ground, or use a "swift." Twists or kinks especially weaken aerial cables.

STORAGE.—Direct sunlight should be avoided. Cool, dry rooms are best for vulcanised rubber; cool, damp rooms for guttapercha; for both, avoid places sometimes damp and sometimes dry.

FIXING.—Metallic staples should not be used, as in driving them into place it is difficult to avoid cutting or bruising the insulation. Sharp bends should only be put into cables protected by stout braid or armouring. Never hammer cables when bending them.

Connecting Up.—The ends of cables, where connected to any apparatus, need to be carefully prepared. The tapes or braids, including the indiarubber-coated tape next the rubber, can absorb and retain moisture, leading in time to leakage along the outside of the cable. To minimise this, remove carefully for three or four inches both braid and tape, taking great care not to cut the rubber. At these uncovered ends, if exposed to strong sunlight, the rubber may deteriorate rapidly; this can be hindered by lapping pure rubber or vulcanising rubber tape over the rubber insulation, these lappings being easily renewed. When testing for insulation, scrape the surface of the rubber at these ends with a sharp knife, and clean it with naphtha, or coat it with clean, newly-melted paraffin wax.

Jointing.—This should be done by skilled men, especially when the joints have to be vulcanised.

Situation.—The situation in which cables are to be fixed determines the nature of the protection necessary for the insulating material upon the cable.

Alternations of dryness and moisture seriously affect the durability of cable; in such places lead-covered cables should be used.

Mines.—Rubber-insulated cables, when employed in mines and pitshafts, generally require to be lead covered, on account of the chemical salts contained in the water of the mine acting injuriously upon the rubber. Where lead-covered cables are not desired we recommend vulcanised bitumen cables. The downtake shaft is best for cables, as the uptake is usually very damp towards the top. Cables passing down shafts should be fixed or supported at short intervals.

Underground Pipes.—Each end of every pipe should be well rounded internally, that cutting edges may not exist when adjacent pipe ends are not quite in line. Internal fins and rough places in wrought-iron pipes are very common, and need to be carefully removed. The insulation may be stripped, or the conductor broken, when cables are being pulled into pipes having the above defects. Before pulling cable in, a ball or template should be pulled through the pipes, to remove any dirt, intruding lead, etc., or tools left in. Cables for pulling into pipes, whether braided or lead covered, need an extra tape or braid.

For use in places where there is any risk of fire, the Helsby Company recommend a special fire-resisting compound, which resists both heat and the action of hot water.

Figs. 114 and 115 show sections of cables made by Callender's Cable and Construction Company Limited. The

Unarmoured. Single-Wire Armoured. Double-Wire Armoured

Fig. 114.—Single Conductors, Callender's Cable and Construction Company Limited.

group in fig. 114 are single conductors, insulated with vulcanised bitumen, unarmoured, single-wire armoured, and

double-wire armoured respectively. Fig. 115 represents three-core three-phase cables similarly insulated and protected.

UNARMOURED. SINGLE-WIRE ARMOURED. DOUBLE-WIRE ARMOURED

FIG. 115.—THREE-CORE THREE-PHASE CABLES, CALLENDER'S CABLE AND CONSTRUCTION COMPANY LIMITED.

The Callender Company do not recommend lead sheathing for mining cables; their experience leads them to advocate vul-

canised bitumen with steel wire armouring where mechanical protection is necessary. To quote their own words:—

The cables available may be divided into two classes:—

1. Cables with hygroscopic dielectrics.
2. Cables with non-hygroscopic dielectrics.

Hygroscopic Cables.—In this class of cable it is usual to depend on a lead sheath for keeping the dielectric dry and free from moisture.

The result of our experience shows that lead-sheathed cables, in nine cases out of ten, are unsuitable for use in pits, owing to the fact that the lead combines so easily with the water that is usually found there, and with which it comes in contact. This chemical action, of course, results in the disintegration of the lead, which is materially assisted by any electrical action that may be taking place, however slight. It is quite obvious, that if disintegration of the lead does take place, and moisture be present, the hygroscopic dielectric will break down, and the cable will consequently fail.

The use of lead-sheathed cables in shafts, apart from the reasons stated above, is not by any means advisable. The weight of the cable is so great that the cost of supporting becomes very considerable; moreover, lead being extremely ductile, the very fact of suspending it vertically will, in all probability, cause the lead to slip and possibly part.

It will therefore be seen from the foregoing remarks that it may be taken as a general rule that lead-sheathed cables are unsuitable for colliery work.

Non-Hygroscopic Cables.—Under this heading come vulcanised bitumen and vulcanised indiarubber cables. Neither of these require a lead sheath, depending as they do solely on the nature of the insulation itself, which is waterproof in both cases.

We do not recommend vulcanised indiarubber cables, except under certain conditions and for certain purposes, as the life of these underground is generally considerably less than that of a vulcanised bitumen cable.

A vulcanised bitumen cable, however, possesses for colliery work advantages which other classes of cable lack in that—

(*a*) There is no lead sheathing liable to disintegration from various causes, as in the case with cables having hygroscopic dielectrics.

(b) It has a longer life, and is also less expensive, than vulcanised indiarubber cable.

There is no doubt that a vulcanised bitumen cable, as made by this company for the last twenty-five years, has proved itself by the test of time the most reliable and satisfactory type of cable for use in pits, and for this reason it has come to be looked upon as the standard for colliery work.

Where vulcanised bitumen cable is to be used in a shaft, it is generally protected by means of two layers of galvanised steel wires, one put on in a right-handed and the other in a left-handed direction.

The size of the armouring, as a rule, is between No. 12 and No. 14 standard wire gauge; under special circumstances they are larger, but generally speaking 12 to 14 is the size we employ for the armouring of cables in a pit shaft.

The armouring is clamped at the top, and at intervals, depending upon the weight of the cable, by means of cleats of stout timber about six feet long. These are placed so as to clamp the cables into position and relieve the strain. Another method of supporting cables in a shaft is to fix a continuous casing from the top to the bottom of the shaft, and to use an unarmoured cable, served with an extra yarn; this cable is then malleted carefully into the grooves, which are so designed that they grip the cable throughout its length.

In the workings, where the risk of mechanical injury is considerable, we usually armour the cable with a single layer of galvanised steel wires; but where no injury is likely to occur the cable is finished off with a stout braid.

Messrs. W. T. Glover & Company Limited insulate their cables with paper impregnated with a compound made from oils, to which they have given the name "Diatrine." An outer covering of vulcanised bitumen is added to make the insulation perfectly waterproof, thus dispensing with the lead sheath. Messrs. Glover also make a fire-resisting compound.

The St. Helens Cable Company Limited advocate the use of a special preparation of vulcanised bitumen, which they call "Dialite," for the insulation of mining cables. It is claimed to possess in a high degree the properties of damp-resisting and durability, as well as high insulation resistance. It is perfectly

waterproof, and the makers refer to cases in which cables insulated with this preparation are working permanently under water, without any outer protection beyond the ordinary tape and braid. Dialite is said to be not easily inflammable.

The St. Helens Cable Company make an ingenious and effective switch box arrangement (fig. 116), intended for use

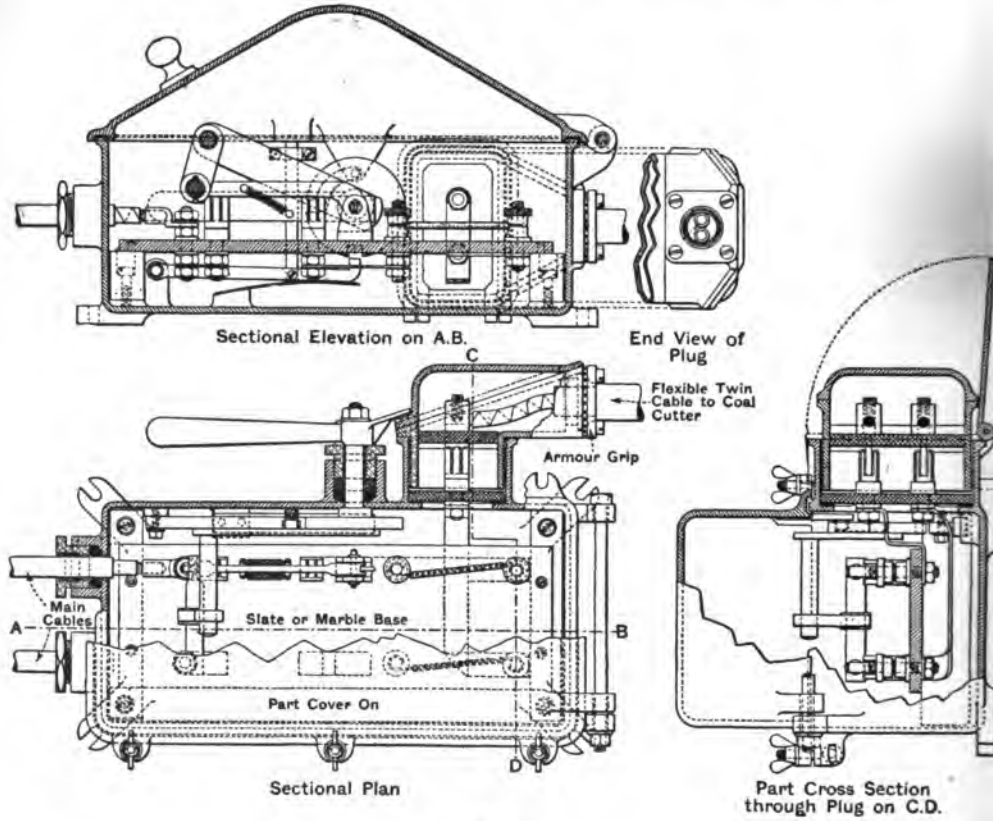


Fig. 116.

The St. Helens Cable Company's Safety Switch Box.

with the flexible trailing cables used in connection with coal-cutting machines. The switch is so contrived that the trailing cable can neither be connected nor disconnected whilst the switch is closed. To connect the cable, or to disconnect it, the switch must first be opened. The cast-iron box is gas tight,

and is so arranged that it cannot be opened whilst the switch is closed, nor, in the event of its being opened, can the switch be closed until the box is closed. It is thus an absolute safeguard against the possibility of a mistake which might lead to serious consequences.

Reference to flexible trailing cables reminds us that whilst these must be specially flexible, they must also be protected against mechanical injury. Steel wire armouring is clearly out of the question. Messrs. W. T. Glover make a flexible trailing cable with leather woven round it. (*See fig.* 117.)

FIG. 117.
MESSRS. W. T. GLOVER'S LEATHER-SHEATHED TRAILING CABLE.

An excellent plan, adopted by the Helsby Company, is to armour the flexible trailing cable with tar-marline; the tarred rope makes a durable and flexible protection, which has the merit of being easily repaired if damaged.

JOINT BOXES AND DISCONNECTING BOXES.

As a general rule, in colliery installations, when a cable has to be jointed, a special joint box is or should be employed. These boxes are not only used for joining together the extremities of long lengths of cable when they are being put in, but also for purposes of repair. Suppose, for example, a fall of roof damages the insulation of a cable, the damaged portion should be cut out, and the connection made good by means of a joint box. If the cable is armoured *the electrical continuity of the armouring must also be restored*, provision being made for this in the box.

Fig. 118 (*see page* 230) shows a joint box, for connecting lengths of three-core three-phase cables, made by the Callender Company. It is specially intended for use in a shaft. The armouring is securely held by means of the clamping arrange-

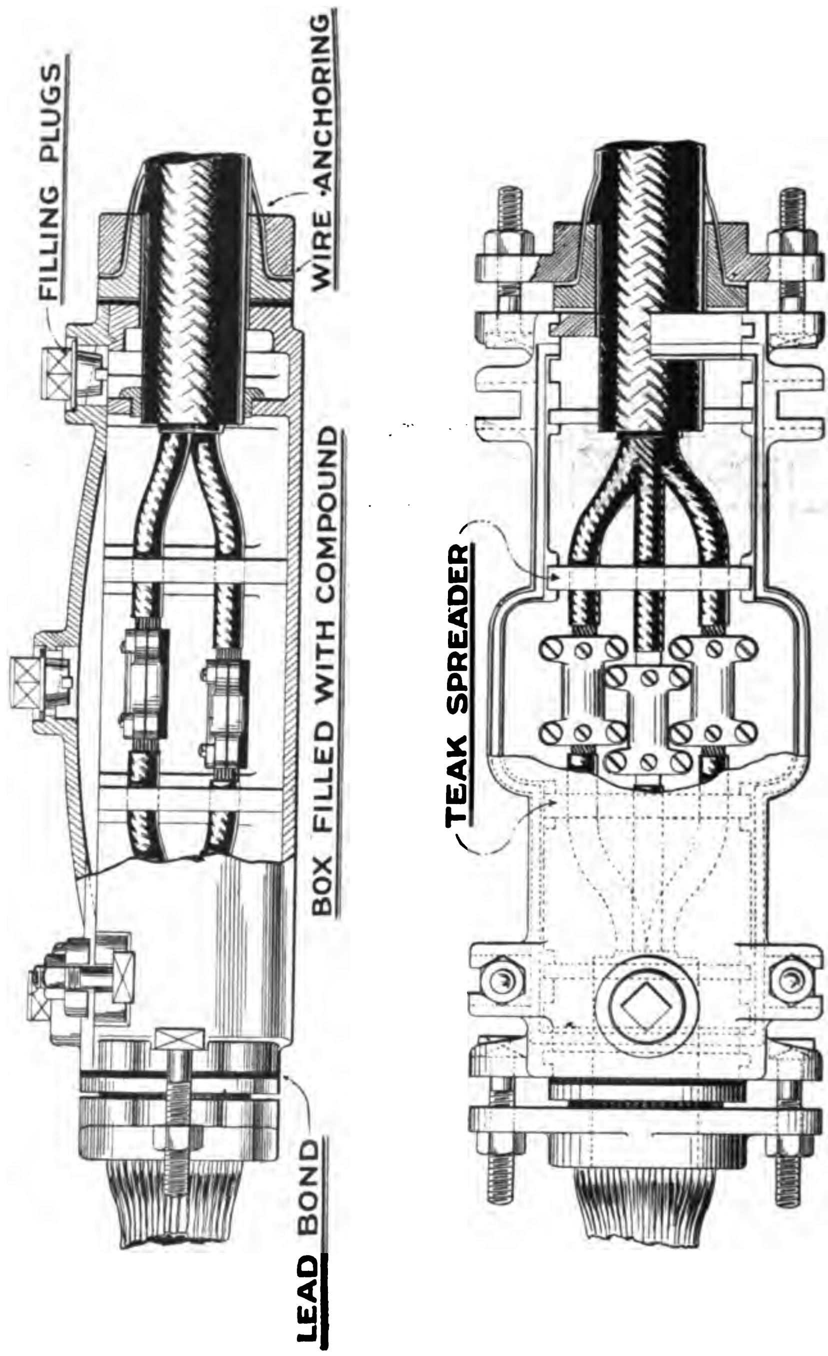


FIG. 118.—NON-DISCONNECTING STRAIGHT JOINT BOX, THE CALLENDER CABLE AND CONSTRUCTION COMPANY LIMITED.

ment, referred to in the sketch as the wire anchoring; the conductors themselves are connected by means of clamps. When the joint is completed the box is filled solid with insulating compound.

Fig. 119 shows the manner in which this joint box is used in the shaft. Clamps grip the cable both above and below the joint box, and these are connected with each other by chains. The bulk of the weight of the cable is carried by the side

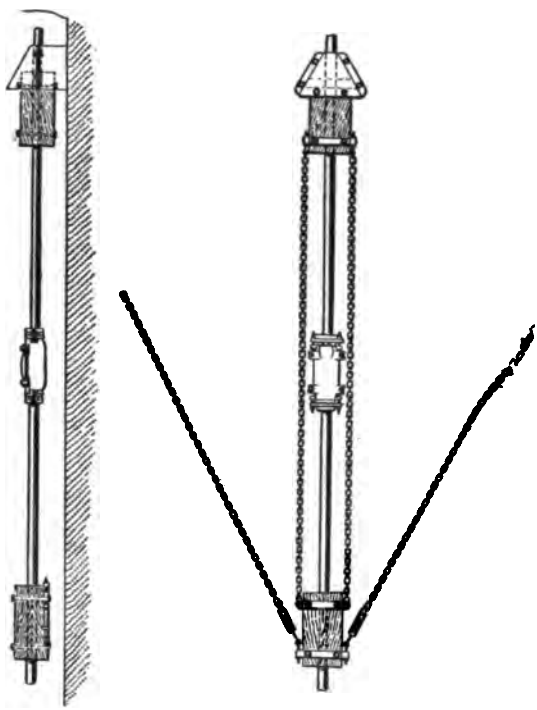


FIG. 119.

CALLENDER'S JOINT BOX FIXED IN SHAFT.

chains attached to the lower clamp and secured to the sides of the shaft. The joint box is thus relieved of any strain.

Where the connection is not intended to be of a permanent character, and convenience is desired for disconnecting a section of the conductor for any purpose, testing, etc., a dis-

connecting box is used. Fig. 120 shows a disconnecting box made by the Callender Company. The cast-iron box is made gas tight and water tight. Provision is made for maintaining the metallic continuity of the armouring. The lower portion

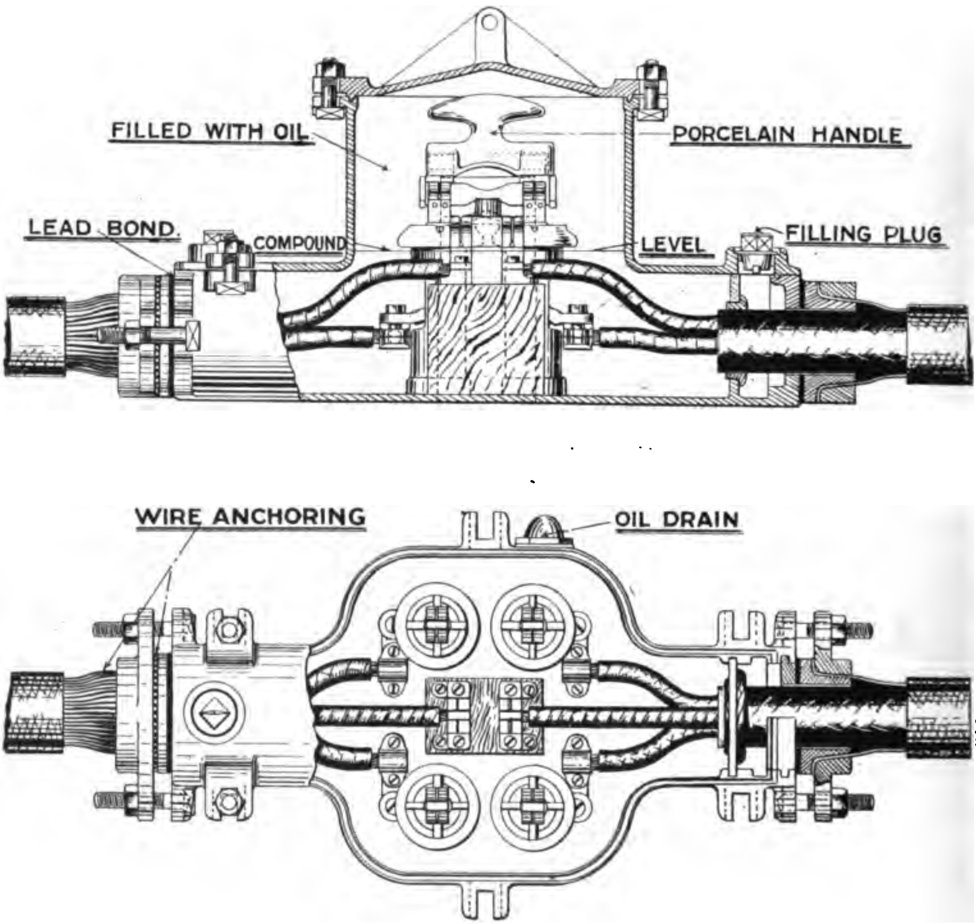


FIG. 120.
CALLENDER'S DISCONNECTING BOX.

of the box is intended to be filled up with insulating compound, and the upper portion filled with oil. The fuse strips which form the connecting links are immersed in the oil, and are fitted with porcelain handles.

Fig. 121 is a straight-link disconnecting box, made by Messrs. W. T. Glover. This particular type, which is both gas

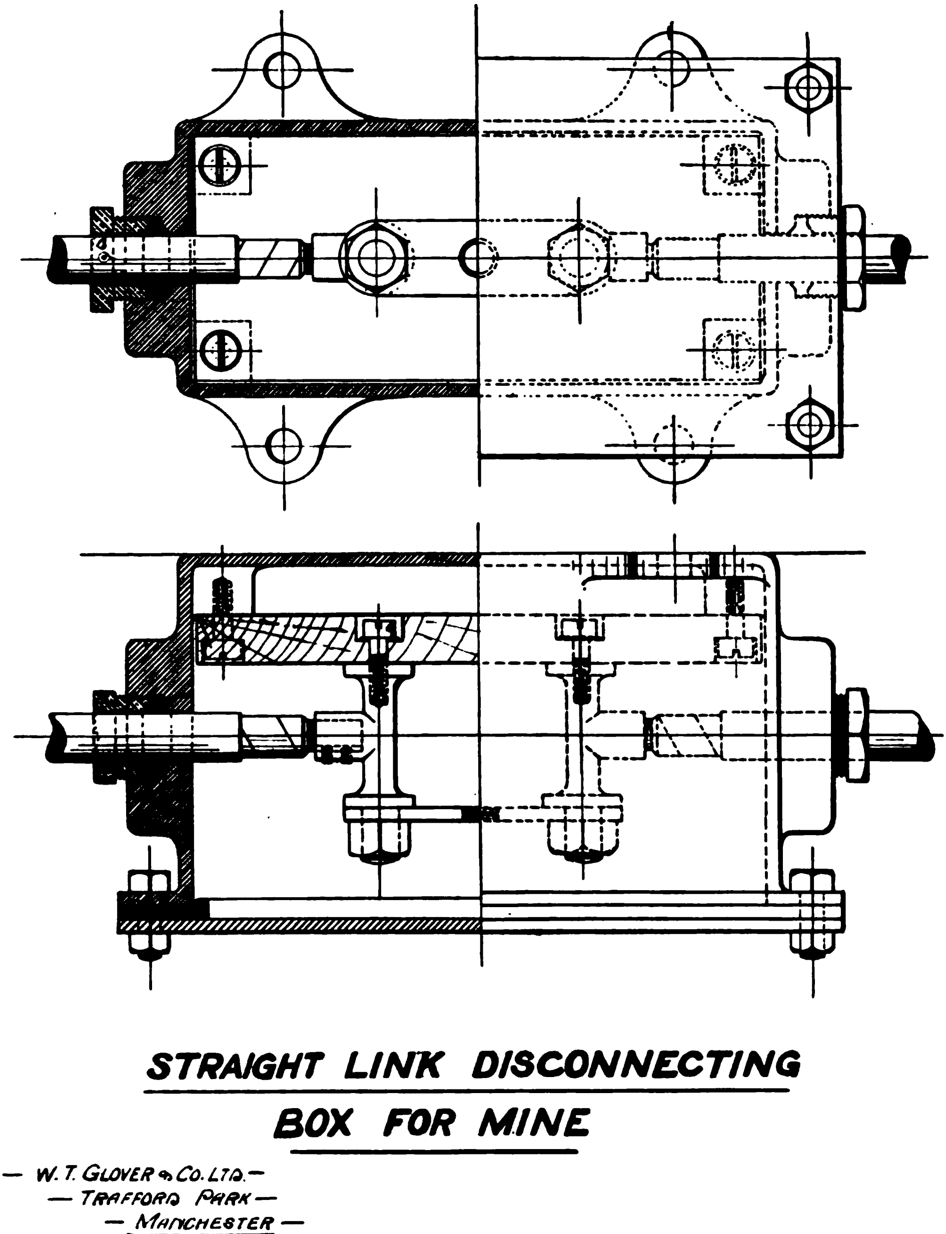


FIG. 121.

and water tight, is intended for attaching to the roof of an underground roadway. The ends of the conductor fit into sockets, where they are secured by screws. A gland and stuffing-

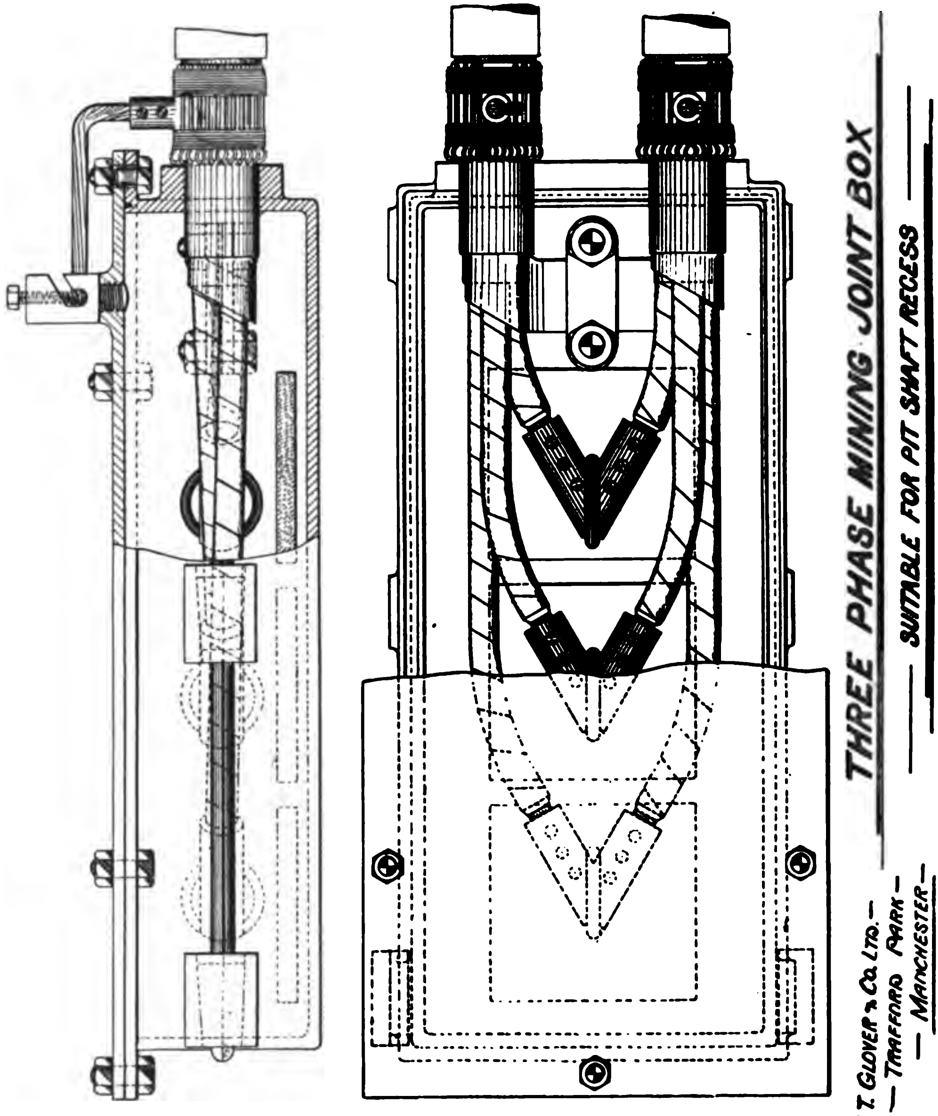


Fig. 122.

box arrangement enables a gas-tight connection to be made where the cables pass through. By removing the bottom cover

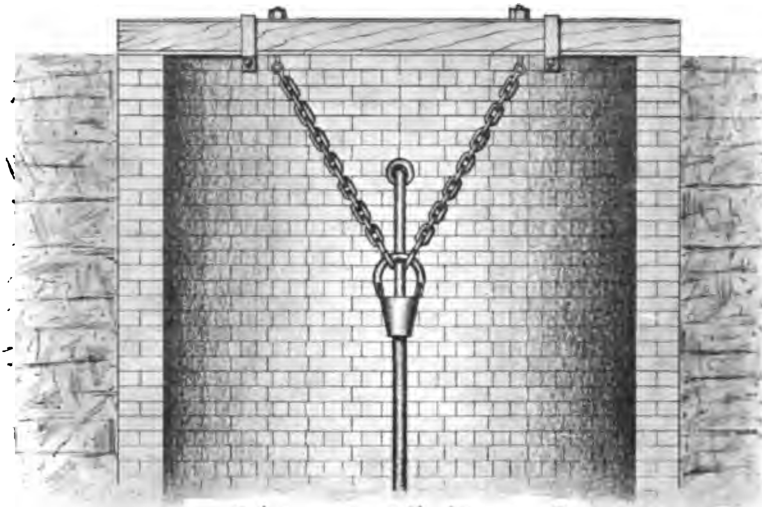
or plate, the interior of the box is accessible for the insertion or removal of the connecting strip between the two nuts. Fig. 122 illustrates a joint box for a three-core three-phase cable, also made by Messrs. Glover. It is intended to be fixed in a recess in the side of the shaft. The two ends of the cable enter the box at the same horizontal plane, and the three cores are coupled by means of angle sockets with set screws. It will be observed that a strand of copper connects the armouring of each cable with the metal of the box, thus ensuring the earthing and the electrical continuity of the armouring. If lead sheathing is employed its continuity must also be restored, for which purpose a clamp is shown inside the box where the cables enter. When the joint is completed the box is filled up solid with insulating compound. This particular joint box was designed for a cable working at 3000 volts.

FIXING CABLES IN SHAFTS AND ROADS.

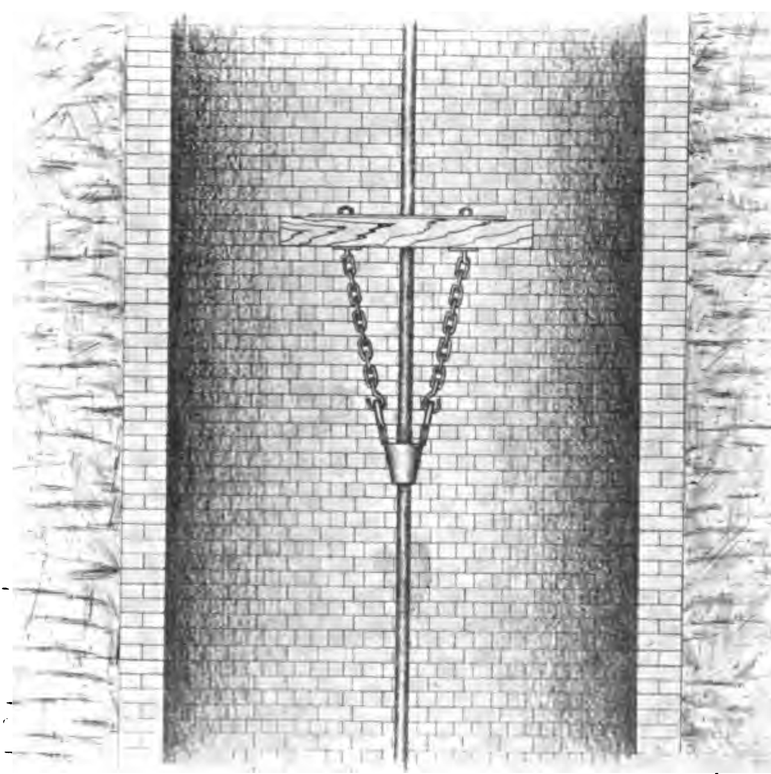
The cables which carry the current down the shaft must be securely supported, and protected from liability to mechanical injury. If the cable is armoured with steel wire the armouring may be made to carry the weight of the cable, either with one support only, at the top of the shaft, or with intermediate supports. An example of the first-named plan is illustrated in fig. 123 (*see page* 236), for which we are indebted to the St. Helens Cable Company, as well as fig. 124 (*see page* 236), showing an intermediate support.

Fig. 125 shows a cleat recommended by the Callender Company. It may be suspended by means of chains, in the manner already illustrated (fig. 119, *see page* 231), or secured to the side of the shaft by bolts let into the brickwork.

An unarmoured cable must be supported throughout its entire length, and no better arrangement exists than that illustrated by the Callender Company in fig. 126 (*see page* 238) and fig. 127 (*see page* 239). This arrangement consists of a continuous wooden casing, extending from the top to the bottom of the shaft. The cables fit sufficiently tightly in the grooves to require some little hand pressure to force them in. The cover, or capping strip, is screwed on, thus further securing and supporting the cables. The casing is secured to the sides of the shaft either in the manner shown in fig. 126 (*see page* 238)—



Method of supporting Cable at top of shaft
Weight entirely borne by Armouring.

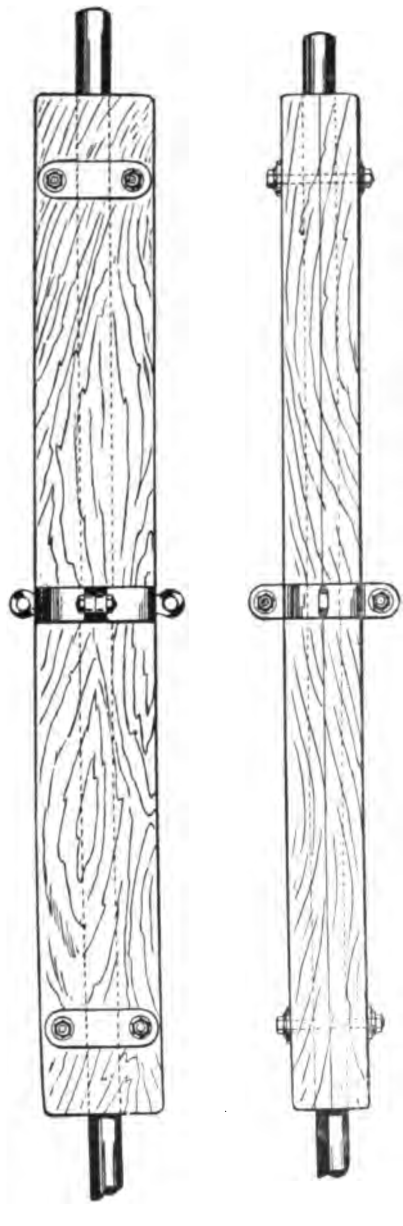


4th Method - Supporting Cable part way down shaft.

FIGS. 123 AND 124.

SHOWING METHOD OF SUPPORTING ARMOURED CABLES IN THE SHAFT, THE ST. HELENS CABLE COMPANY LIMITED.

rag bolts let into the brickwork—or by means of the clamps (fig. 127, *see page* 239), which secure the casing to bearers in the shaft.



CLEAT.

FIG. 125.

CLEAT FOR SUPPORTING CABLE IN SHAFT.

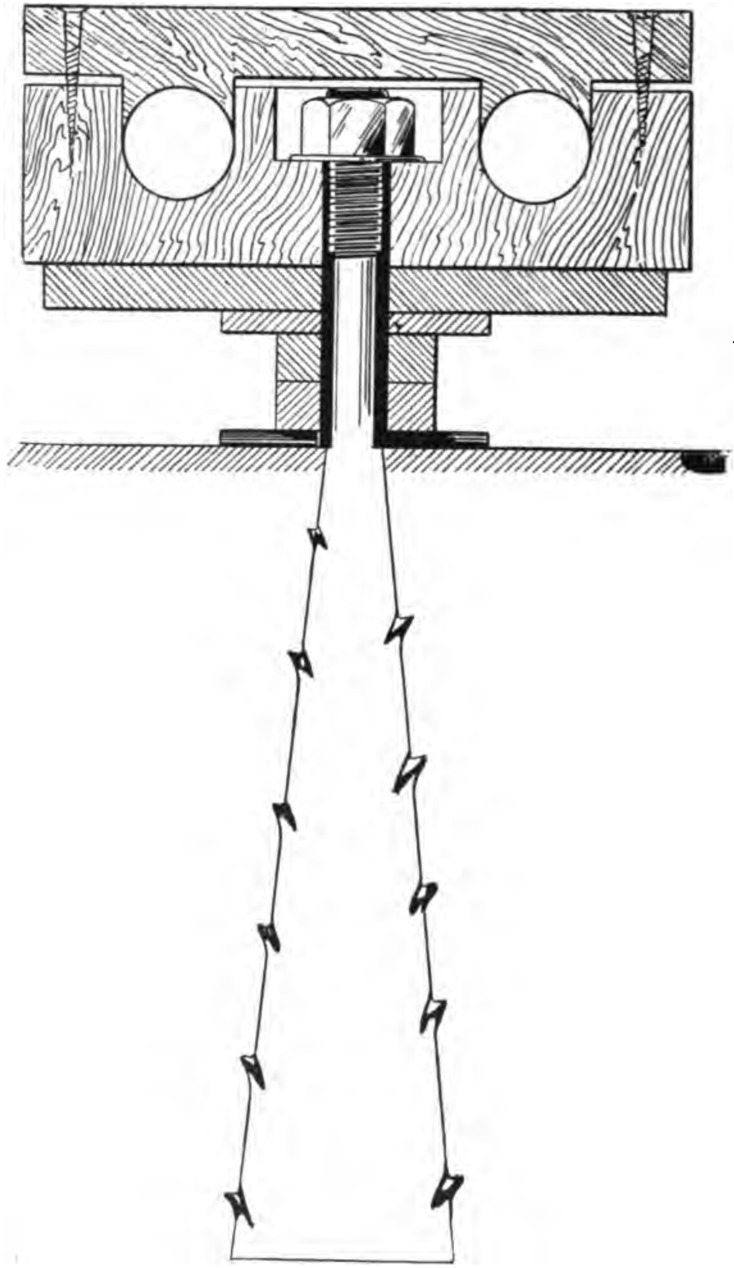


FIG. 126.
CASING FOR CABLES IN THE SHAFT.

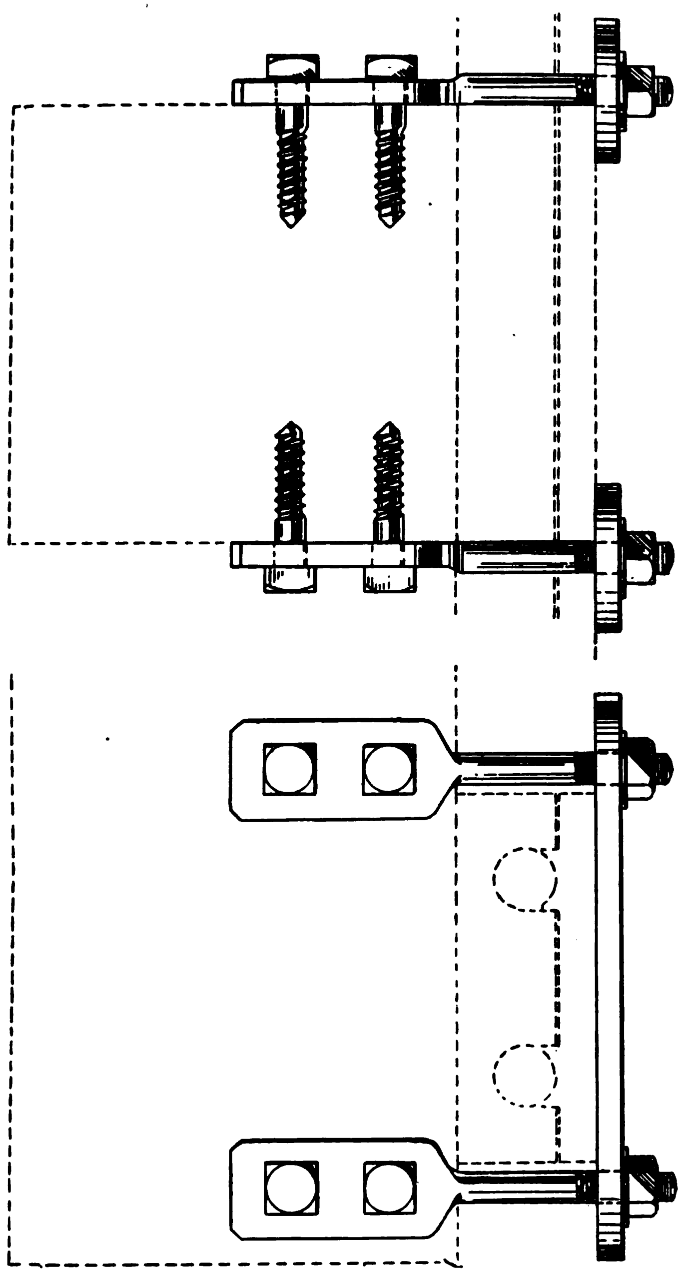


Fig. 127.
Casing Secured to Bearers in the Shaft.

In the roadways any of the methods illustrated by the St. Helens Cable Company in fig. 128 may be adopted. The following are the company's observations on these different methods:—

ROAD CABLES.

First Method.—Single unarmoured cables, taped, jute yarned, and braided, laid either on a shelf cut in the wall or in a trough laid behind the props; the trough should, if possible, be filled with bitumen. This method is, we find, far superior to any other, although rather expensive. It is, in addition, very safe, as there is no risk of personal contact.

Second Method.—Unarmoured single cables suspended with tarred twine behind the props or, where the roof is good, laid on a shelf cut in the side. All cables not laid in the floor should be put behind the props.

Third Method.—Armoured cables—singles for continuous, twin for alternating, and three-core for three-phase—suspended either from the props (in front) or from the roof timbers. We do not recommend this method in any way; its only merit is cheapness and ease of erection. It is useless and dangerous to use insulators for supporting this class of cable.

Fourth Method.—Armoured cables laid direct in the floor, or unarmoured cables laid in troughing in the floor. This is a most excellent method, but very expensive, and upsets the working of the road; also provision must be made for a rising floor by leaving slack in brick chambers near the joint boxes.

Where armoured cables are used in a road it is absolutely essential that the armouring should be continuous and remain so, all branches and repairs being bridged over in a substantial manner with copper or iron strand firmly clamped to the armouring. No mere twisting of one wire round the armour to be allowed. Further, the armour ought to be earthed every hundred yards in a substantial manner to water pipes. If there are no water pipes in that particular road, then an old steel rope should be laid in the floor to take its place, the rope being connected to water pipes at the first opportunity. All machines, motors, winding gears, etc., ought to be earthed in the same manner. The frequent earthing is necessary, as the joining up of the armour at the repairs and joints may become defective in time, and a damage in that length would render the armour alive.

Armouring is undoubtedly useful in saving the insulation

Second M

First M

Thre

from small damages, but under a severe blow, piercing the insulation, a flash is the result before the fuses blow; whereas with unarmoured cable no flash results, as the leakage at the damage is only two or three amperes; but if this leak is not repaired smouldering may result. Therefore, after every fall of roof, the cables should be carefully examined and any damaged spots repaired with "N" tape. Also the mine electrician should make a test of the insulation of the cables by themselves, all motors being disconnected, and must not be content with a fairly high insulation, but must get the same as before the fall or find out the reason for the drop.

An insulation test as above should be made every week, and a proper record kept; the mines inspector ought to see this book at every visit.

FIG. 129.
GLOVER'S PATENT CABLE SUSPENDER.

Generally speaking, the plan which appears to be the best and most convenient is to loosely suspend the cables from the road timbers, with plenty of slack between the points of suspension, by means of loops of leather (*see fig.* 129), tarred twine, or anything which will allow the cable to break away before any serious strain can be put upon it by a fall of roof. The Callender Company have brought out a simple and effective

cable suspender, or clip, suitable for armoured cables, shown in fig. 130. The dog, or spike, is driven into a prop, and the spring clip slipped over the cable. It will be seen that any undue strain forces the cable out of the clip, which is always ready to be re-attached.

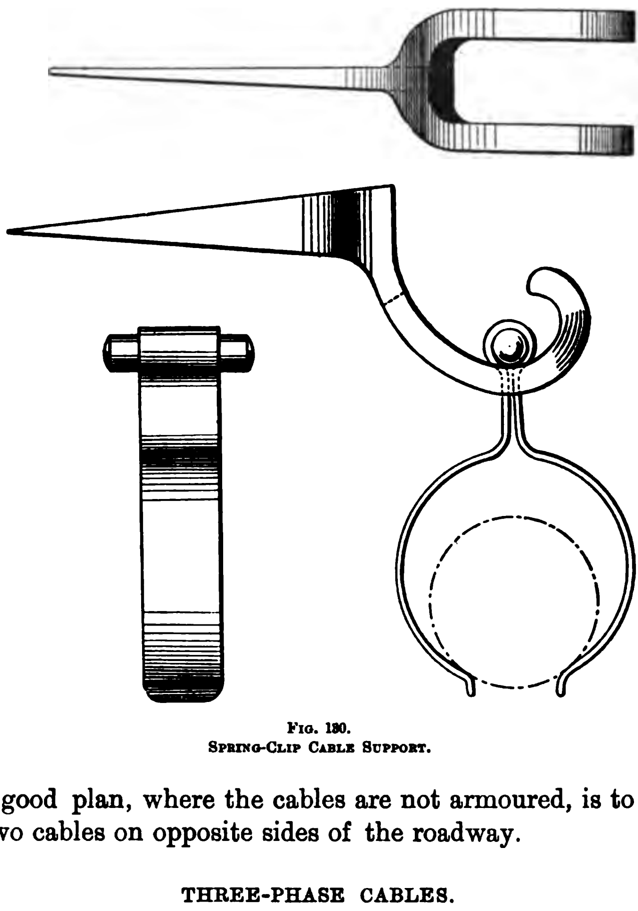


FIG. 130.
SPRING-CLIP CABLE SUPPORT.

A good plan, where the cables are not armoured, is to carry the two cables on opposite sides of the roadway.

THREE-PHASE CABLES.

For the distribution of three-phase alternating current, either three single cables are employed or a three-core cable. It must be clearly understood that if the conductors used in a three-phase system require to be either lead-sheathed or armoured, the metallic covering *must enclose all three conductors* within the one armouring. It is not permissible to armour each conductor separately; the result would be an excessive loss of

energy due to inductive resistance. Similarly, if at any point the three-phase conductors have to be carried through metal pipes, they must *all pass through the same* pipe, and not through three separate pipes.

It is important that careful tests of the insulation of the system be made at stated intervals, for which purpose a special testing set is provided. When a length of cable has been tested for insulation resistance, it is necessary to *multiply* the resistance by the length of the cable *in miles*, in order to get the insulation resistance in megohms per mile.

For example: Suppose a piece of cable, quarter of a mile long, shows an insulation resistance of 2400 megohms—$2400 \times \frac{1}{4} = 600$ megohms per mile. Similarly, a cable three miles long gives an insulation test of 200 megohms—$200 \times 3 = 600$ megohms per mile.

A COMPLETE ELECTRICAL INSTALLATION UNDERGROUND.

While most ordinary electrical installations in collieries have perhaps lost the interest of novelty, it is conceded that the application of the new power agent is far from having attained maturity, and many lessons are to be learnt from such plants as that of the United National Collieries at Wattstown, in the Rhondda Valley. The power requirements of these pits are very large, the workings being of considerable extent, and the three main haulage roads at present each over a mile in length. In deciding upon the electrical equipment of the pits, the extreme elasticity of the electrical system, and the ease and economy with which it can be extended, were not lost sight of; the importance of these considerations, in a rapidly developing property, is too often underestimated. Favourable terms for the supply of current having been arranged with the South Wales Electrical Power Distribution Company, plans for the installation were drawn up, and the offer of Messrs. Bruce, Peebles & Co. Ltd., of Edinburgh, London, and Cardiff, to design, manufacture, and erect the entire plant was accepted. The work included the solution of several novel problems, and the experience of the contractors in mining work stood them in good stead.

The No. 1 and No. 2 pits of the United National Company are both 480 yards deep, and the No. 1 is at present being sunk 110 yards deeper. In connection with this work a small double-

drum sinking gear has been recently installed, driven by a totally enclosed 30-horse power Peebles polyphase motor,

Fig. 181.

An Electrically-operated Winding Gear for Sinking at the No. 1 Pit of the United National Company, Wattstown, driven by means of a 30-h.p. Bruce Peebles Three-Phase Motor.

running at 720 revolutions per minute. (*See fig.* 131.) This gear raises the skip full of rubbish, a maximum weight of $1\frac{3}{4}$ tons, at a speed of about 300 feet per minute. The

controller, which is also shown in the photograph, is of the liquid type, and the motor is thus accelerated absolutely uniformly and without jerks; this is desirable, as obviating the risk of material being jerked out of the skip, while it also adds to the comfort of men being lowered or raised. A valuable point in this motor-driven gear is that it is very portable, and can be readily transferred from level to level as required.

The pumping installation in the mine has been carried out more or less on standard lines, and includes in all five large pumps, all driven by polyphase motors. We may here mention that the United National is the first pit in the Rhondda Valley district to be entirely equipped underground with electrically-driven machinery. The steam engine which formerly operated one of these pumps has been supplanted by an 80-horse power Peebles three-phase motor, having totally enclosed slip rings. The controller for this motor has been liberally designed, so that it is possible to run for lengthy periods at a reduced speed. The pump is of the horizontal three-throw pattern, capable of raising 125 gallons per minute against a head of 1000 feet; the rams are $4\frac{1}{2}$ inches diameter by 12-inch stroke, and the motor runs at a speed of 490 revolutions per minute. The above pump is located at 4-foot landing at the bottom of No. 1 pit, and pumps up to a sump in the No. 2 Rhondda seam, where there are installed two similar horizontal pumps raising 150 gallons per minute against 320-foot head, driven each by a 30-horse power motor of similar type to the above. The remaining two pumps are at the bottom of No. 2 shaft and in the "Bull" working respectively, and these are of the vertical type, the arrangement being otherwise similar to the other three pumps. (*See fig.* 132, *page* 246.)

The principal interest, however, of the installation undoubtedly centres in the three very large motor-driven haulage gears. Of these we will deal first with the south-side haulage, which is in a large underground room close to the pit bottom. It is believed that this is the largest haulage gear driven by a polyphase motor which has ever been installed in the United Kingdom. The haulage was originally driven by a pair of twin-coupled simple engines, 18 inches diameter by 30-inch stroke. These engines were still in place when the motor was installed, and it was therefore temporarily placed above

the haulage gear. Fig. 133 shows the motor in its elevated position. It is now intended to take the engines out, and

Fig. 132.
An Electrically-driven Three-Throw Pump, Bruce, Peebles 30-H.P. Three-Phase Motor.

to bring the motor down behind the drums of the haulage gear, when the arrangement will, of course, be much more compact, and will display the advantages of electric driving for haulage gears to greater advantage. It is, perhaps, need-

less to point out to colliery men that had a motor-driven haulage been put in in the first instance, the engine room

FIG. 188.

A 250 B.H.P. BRUCE, PEEBLES THREE-PHASE MOTOR, OPERATING HAULAGE GEAR.

need not have been more than half as big, saving a great amount of excavation. The road worked by this gear is

upwards of 1800 yards in length, and the usual load worked consists of 22 trams, each weighing, loaded, 2 tons. The grade varies considerably, the maximum of 7 inches in the yard being reached at points, the location of which will be readily determined upon examination of the load curve of this haulage reproduced in fig. 134. The motor has a nominal capacity of 250 horse power, but as will be seen from the curve, it works for short periods up to 500 horse power without

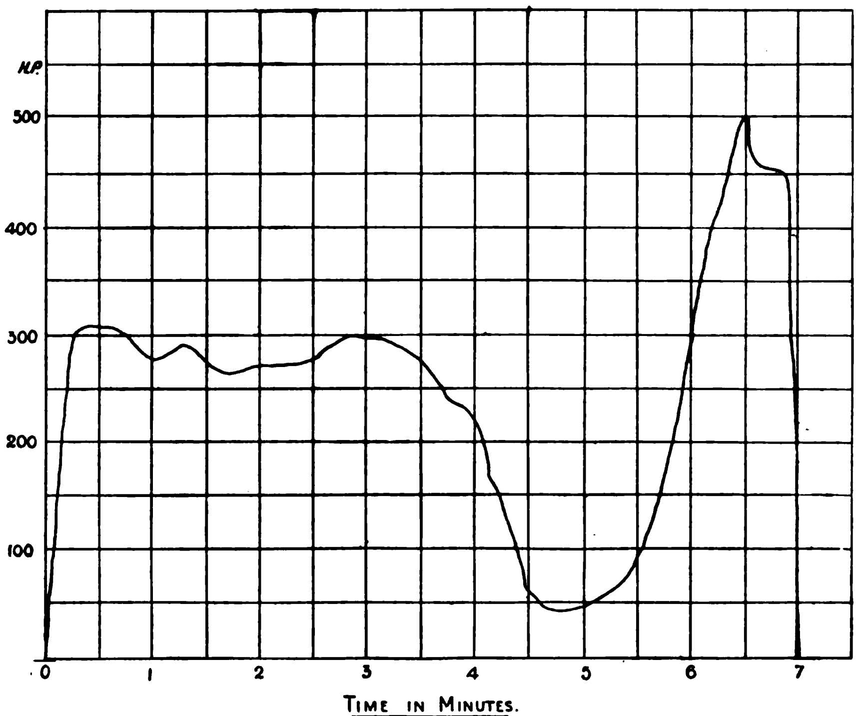


FIG. 134.
LOAD CURVE OF 250 B.H.P. POLYPHASE HAULAGE MOTOR.

serious diminution in speed. The voltage is 500, and the speed 860 revolutions per minute. Double reduction gearing is of course used, the first gear and pinion being machine-cut; this gives a speed of rope of nine miles per hour. On the second shaft is an auxiliary brake, by the aid of which the gear can be stopped immediately, in order to allow the shackle of the trams to drop off the haulage rope at the end of the haul, when the latter run round a sharp curve at right angles to the

line of hauling by their own momentum. The controller used for this haulage is of exceptionally-heavy construction, and of the liquid type. The design for this controller presented

FIG. 185.
THE NORTH-SIDE HAULAGE GEAR AT THE UNITED NATIONAL COMPANY'S COLLIERY, OPERATED BY A 150 B.H.P. BRUCE, PEEBLES THREE-PHASE MOTOR.
THE GEAR WAS FORMERLY STEAM-DRIVEN; THE STEAM ENGINE IS VISIBLE IN THE BACKGROUND.

peculiar difficulties, on account of the fact that it is, of course, necessary for the loaded trams to be accelerated gradually and without jerking, in order to avoid shaking coal off, and it is also

necessary at times to run for long periods at reduced speed. In this connection it is satisfactory to note that the motor-driven gear gives a far more steady speed of rope than was possible when the steam engine was used, and much less coal is shaken off the trams, which is good both for the owner and the collier. By operation of the controller handle the speed of haul can be varied from dead slow to full speed with perfectly smooth gradation. It has often been argued, in opposing the introduction of electric driving for haulage gears, that motors are not suited for the purpose, as they are unable to meet the great strain required to pull trams back on to the track after derailment. This argument is quite refuted in the gears in question, as the motors in each can exert a torque of more than double the normal full load torque at a creeping speed. There is thus no difficulty in pulling trams back on to the line, even should a number be derailed and props knocked down.

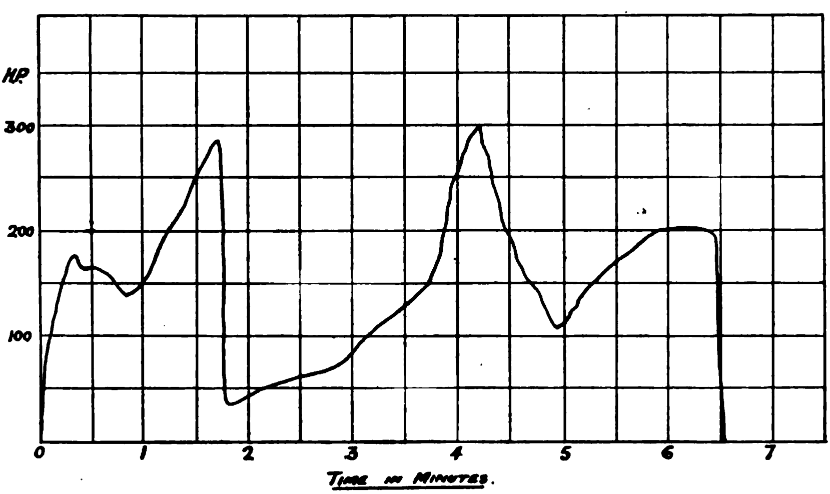


Fig. 136.
Load Curve of 150 b.h.p. Polyphase Haulage Motor.

The north-side haulage (*see fig.* 135, *page* 249) is a similar plant to the above, the road being 1800 yards in length, and the maximum gradient 3½ inches to the yard. The original haulage was driven by twin-coupled 16-inch by 24-inch engines, and the motor replacing them is nominally of 150 horse power, running at 490 revolutions per minute, driving the drums through double reduction gear. From the curve, fig. 136,

however, it will be seen that this motor, also, is working regularly on momentary overloads of 100 per cent; that is, it exerts at times as much as 300 horse power. The speed

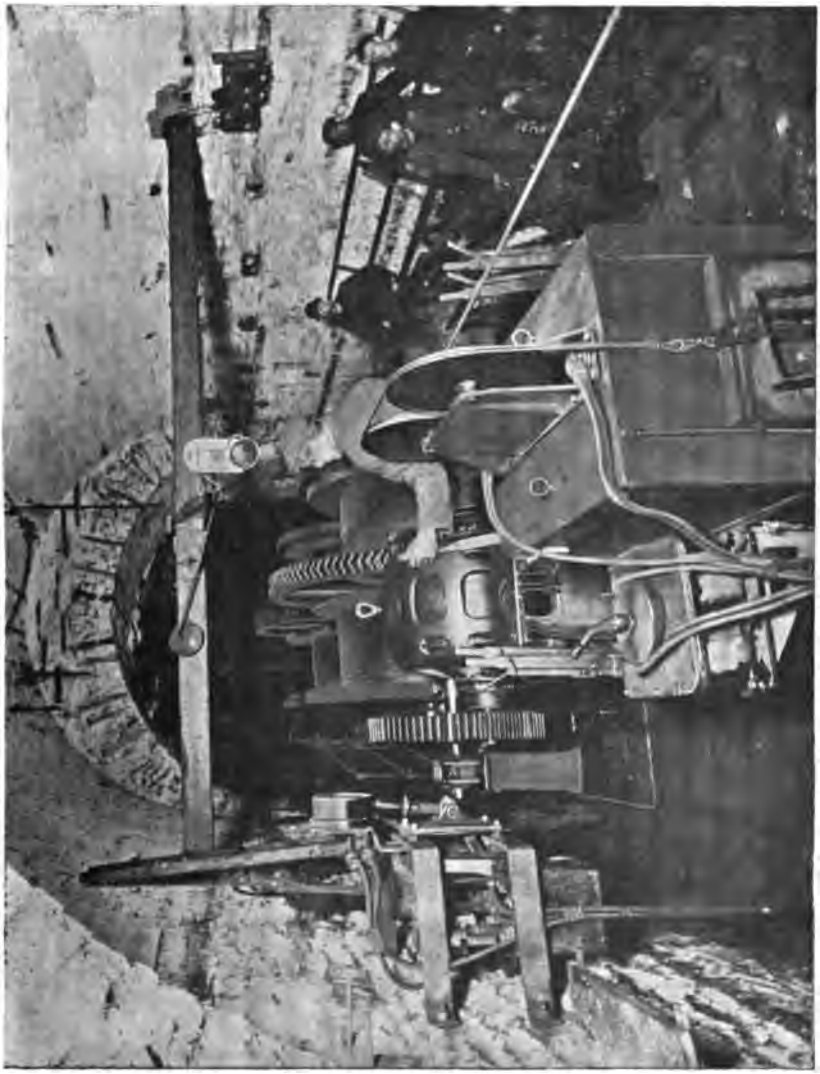


FIG. 137.
A FOUR-DRUM HAULAGE GEAR, OPERATED BY A 150 B.H.P. BRUCE, PEEBLES THREE-PHASE MOTOR.

of rope in this case varies from nothing to $8\frac{3}{4}$ miles per hour, and the load is 20 trams, weighing, loaded, 40 tons. The motor is started under full load, and the speed varied by a

similar controller to that used on the south-side haulage. The north-side haulage is utilised to haul from both the 4-foot seam and the 2-foot 9-inch seam. The latter is 22 yards above the

Fig. 138. A Four-Drum Electrically-operated Haulage Gear.

former, and a hard header has been driven to connect the two.

The third haulage (*see fig.* 137, *page* 251, *and fig.* 138) is interesting, in that while the other two are of the ordinary

two-drum main-and-tail type, the third is a four-drum gear, all the motions being controlled by jaw clutches and driven through double-reduction gearing by a nominal 150-horse power motor, which, however, is being replaced by one of 250 horse power, in order to work heavier loads. The long road-running in-bye from the haulage is 1800 yards in length, and the maximum gradient is 3½ inches per yard. The shorter road has a very severe gradient, but is much shorter, and only empty trucks are raised on it.

The switch gear used in connection with the three haulages is substantially the same, consisting in each case of a main cut-off switch and an automatic circuit breaker, which operates in case of dangerous overload. Both of these are gas tight enclosed. The slip rings of all the motors are totally enclosed, and an ammeter indicates the current used in each case.

Fig. 139 (*see page* 254) shows the method adopted for carrying the three 500-volt three-core cables down the pit. Each conductor is ·2 square inch in area, and insulated by jute and bitumen. Heavy wooden cleats, as shown, are arranged every 10 yards down the shaft.

As already mentioned, the power supply is obtained from the South Wales Electrical Power Distribution Company, and there is a small substation at bank, containing three 500 kilowatts transformers and the necessary switch gear.

As showing the good work which the motors are now doing, it may be interesting to note that while the total nominal horse power of motors installed is 730, the maximum demand is no less than 1100 horse power. The number of units used per 24 hours is approximately 3200, varying, of course, from day to day. The haulages are only worked continuously through the day, comparatively few hauls being made at night. It is interesting to note that the colliery officials and engineers are loud in praise of the way in which the new motive power deals with the coal. The whole journey of trams is started without the least shock or jar, and the time occupied in haulage is about 30 per cent less than with steam, the output being accordingly increased.

It is notable that the ventilation of the pit has been very greatly improved by the elimination of the steam range and the exhaust steam from the haulage and pumping engines. The

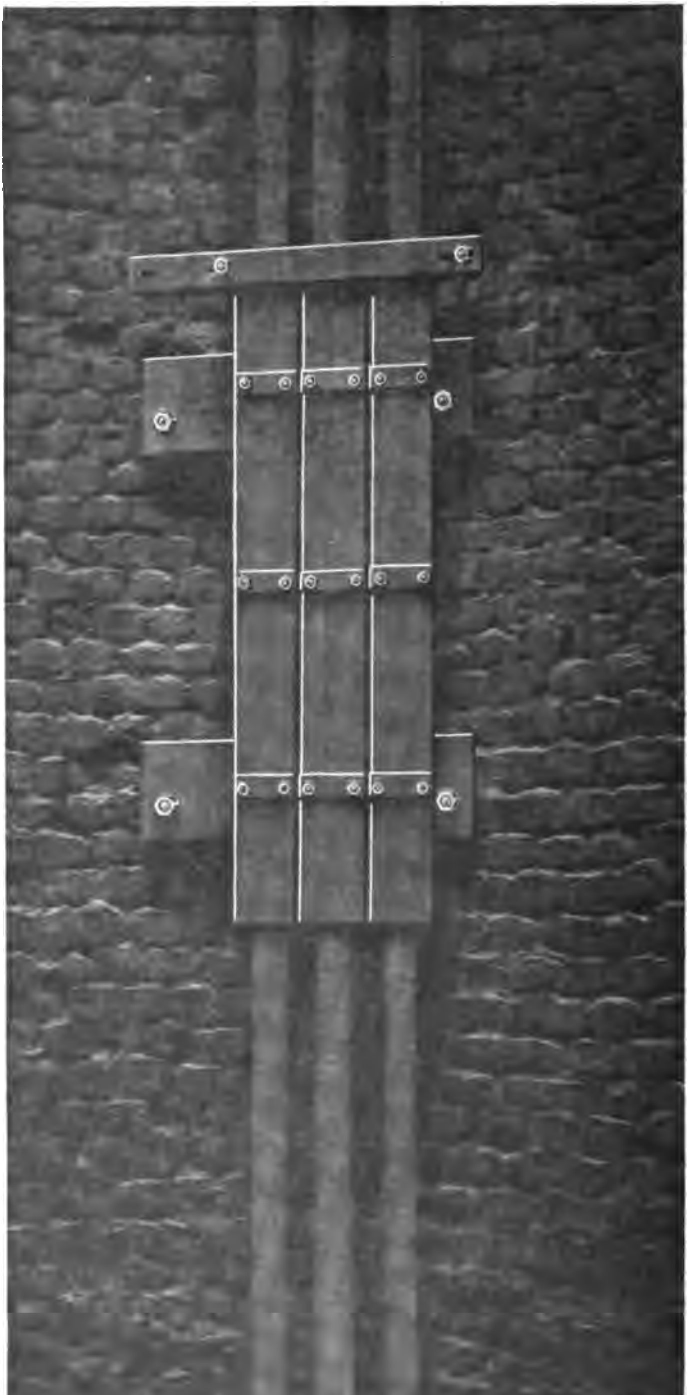
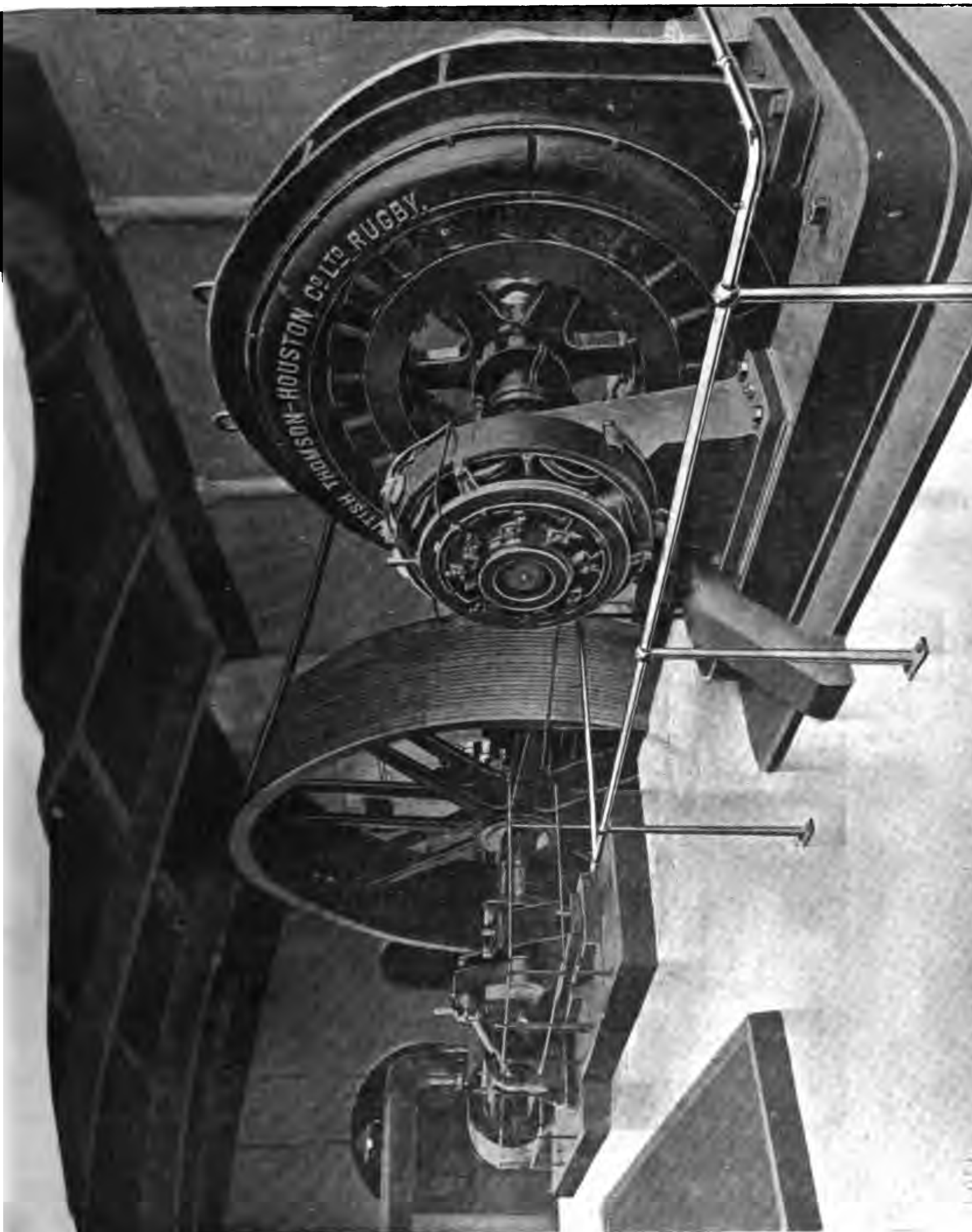


FIG. 189.
CABLES SECURED BY CLEATS IN THE SHAFT.


THOMSON-HOUSTON Co LTD RUGBY.

elimination of the exhaust steam is a special advantage, as in the South Wales Collieries the presence of exhaust steam rapidly deteriorates the top of the rooms and roads, so that it is necessary to be continually repairing these. Since the introduction of electric motors at the colliery in question it has been much easier to keep the roof up. Owing to the removing of the 9-inch steam main from the No. 2 upcast pit, two cages can now be used, and arrangements are being made for installing them. At present only one cage is in use.

The plant was designed and erected throughout under the supervision of Messrs. Bramwell & Harris, as consulting engineers, and was erected under difficult conditions by Mr. J. Pitkeathly, and Mr. How, resident engineer for Messrs. Bruce, Peebles in Cardiff.

We are indebted to Messrs. W. T. Glover & Company Limited Trafford Park, Manchester, for permission to reproduce the following tables:—

DETAILS OF CONDUCTORS,

Showing dimensions, capacity, resistance, and weight.

Size.	Amperes at 1000 per square inch at above ratio, Loss ≐ approx. 2¼ volts per 100 yards.	Amperes at I.E.E. Standard.	Diameter	Area.	Standard Resistance at 60 degrees Fahr.		Standard Weight.		Size.
S.W.G.			Inches.	Square inches.	Ohms per 1000 yards.	Ohms per Mile.	Pounds per 1000 yards.	Pounds per Mile.	S.W.G.
22	0·6158	1·7	·028	·0006158	39·05	68·72	7·120	12·53	22
21	0·8042	2·2	·032	·0008042	29·90	52·62	9·301	16·37	21
20	1·0179	2·6	·036	·001018	23·62	41·57	11·77	20·72	20
19	1·2566	3·2	·040	·001257	19·13	33·67	14·53	25·58	19
18	1·8096	4·2	·048	·001810	13·28	23·38	20·93	36·83	18
17	2·4630	5·4	·056	·002463	9·762	17·18	28·48	50·12	17
16	3·2170	6·8	·064	·003217	7·478	13·16	37·20	65·47	16
15	4·0715	8·2	·072	·004072	5·904	10·39	47·09	82·87	15
14	5·0265	9·8	·080	·005027	4·784	8·419	58·13	102·3	14
13	6·6476	12·4	·092	·006648	3·617	6·366	76·88	135·3	13
12	8·4949	15·0	·104	·008495	2·831	4·982	98·24	172·9	12
11	10·568	18·0	·116	·01057	2·275	4·004	122·2	215·1	11
10	12·868	21·0	·128	·01287	1·868	3·228	148·8	261·9	10
9	16·286	27·0	·144	·01629	1·476	2·598	188·4	331·5	9
8	20·106	31·0	·160	·02011	1·195	2·104	232·5	409·2	8
7	24·328	36·0	·176	·02433	·9881	1·739	281·3	495·1	7
6	28·952	42·0	·192	·02895	·8307	1·462	334·7	589·1	6
5	35·298	48·0	·212	·03530	·6813	1·199	408·2	718·4	5
4	42·273	57·0	·232	·04227	·5688	1·001	488·8	860·2	4
3	49·875	64·0	·252	·04988	·4821	·8484	576·7	1015·0	3
2	59·828	75·0	·276	·05983	·4019	·7073	692·0	1218·0	2
1	70·685	85·0	·300	·07069	·3402	·5987	817·6	1439·0	1
1/0	82·447	97·0	·324	·08245	·2917	·5133	958·4	1678·0	1/0
2/0	95·114	108·0	·348	·09511	·2528	·4450	1099·0	1935·0	2/0
3/0	108·68	120·0	·372	·1087	·2212	·3893	1257·0	2212·0	3/0
3/0	125·66	135·0	·400	·1257	·1913	·3367	1453·0	2558·0	4/0
5/0	146·57	155·0	·432	·1466	·1640	·2887	1695·0	2983·0	5/0
6/0	169·09	173·0	·464	·1691	·1422	·2503	1955·0	3441·0	6/0
7/0	196·34	196·0	·500	·1963	·1225	·2156	2270·0	3995·0	7/0

The above resistances and weights of conductors are subject to a variation of 2 per cent.

Size. S.W.G.	Amperes at 1000 per square inch.	Amperes at I.E.E. Standard.	Diameter of each Wire, in inches.	Diameter of Strand, in inches.	Effective Area: viz., Area of Solid Wire having same Conductivity. Square inches.	Standard Resistance at 60 degrees Fahr. Ohms per 1000 yards.	Standard Resistance at 60 degrees Fahr. Ohms per Mile.	Standard Weight. Pounds per 1000 yards.	Standard Weight. Pounds per Mile.	Size. S.W.G.
3/25	·9311	2·452	·020	·043	·0009311	52·82	45·45	11·04	19·42	3/25
3/24	1·127	2·868	·022	·047	·001127	21·33	37·55	13·35	23·49	3/24
3/23	1·341	3·307	·024	·052	·001341	17·94	31·57	15·89	27·96	3/23
3/22	1·825	4·258	·028	·060	·001825	13·18	23·19	21·62	38·05	3/22
3/21	2·384	5·301	·032	·069	·002384	10·09	17·75	28·24	49·71	3/21
3/20	3·016	6·444	·036	·078	·003016	7·972	14·03	35·75	62·92	3/20
3/19	3·725	7·644	·040	·086	·003725	6·455	11·36	44·14	77·68	3/19
3/18	5·364	10·31	·048	·103	·005364	4·482	7·889	63·52	111·8	3/18
7/25	2·177	4·921	·020	·060	·002177	11·05	19·44	25·70	45·23	7/25
7/24	2·633	5·751	·022	·066	·002633	9·131	16·07	31·08	54·71	7/24
7/23	3·135	6·636	·024	·072	·003135	7·670	13·50	37·00	65·12	7/23
7/22	4·266	8·543	·028	·084	·004266	5·636	9·920	50·36	88·63	7/22
7/21½	4·896	9·565	·030	·090	·004896	4·910	8·643	57·84	101·8	7/21½
7/21	5·571	10·63	·032	·096	·005571	4·316	7·596	65·79	115·8	7/21
7/20½	5·925	11·19	·033	·099	·005925	4·059	7·143	70·0	123·2	7/20½
7/20	7·052	12·90	·036	·108	·007052	3·410	6·001	83·3	146·6	7/20
7/19	8·708	15·34	·040	·120	·008708	2·761	4·860	102·8	180·9	7/19
7/18	12·54	20·68	·048	·144	·01254	1·918	3·375	148·0	260·5	7/18
7/17	17·06	26·62	·056	·168	·01706	1·410	2·480	201·4	354·5	7/17
7/16	22·27	33·12	·064	·192	·02227	1·080	1·900	263·2	463·1	7/16
7/15	28·22	40·22	·072	·216	·02822	·8523	1·500	333·1	586·2	7/15
7/14	34·83	47·80	·080	·240	.03483	·6903	1·215	411·1	723·6	7/14
7/13	46·05	60·10	·092	·276	·04605	·5222	·9190	543·8	957·1	7/13
7/12	58·84	73·47	·104	·312	·05884	·4086	·7192	694·9	1223·0	7/12
7/11	73·22	87·90	·116	·348	·07322	·3284	·5780	864·8	1522 0	7/11
7/10	89·17	103·3	·128	·384	·08917	·2697	·4746	1053·0	1853·0	7/10
7/9	112·9	125·4	·144	·432	·1129	·2131	·3750	1332·4	2345·0	7/9
7/8	139·3	149·0	·160	·480	·1393	·1726	·3037	1644·3	2894·0	7/8
7/6	200·6	200·9	·192	·576	·2006	·1199	·2110	2367·6	4167·0	7/6
19/22	11·57	19.36	·028	·140	·01157	2·079	3·659	136·8	240·8	19/22
19/21	15·10	24·09	·032	·160	·01510	1·592	2·802	178·7	314·6	19/21
19/20	19·12	29·23	·036	·180	·01912	1·257	2·213	226·3	398·3	19/20
19/19	23·60	34·74	·040	·200	·02360	1·019	1·793	279·4	491·7	19/19
19/18	33·99	46·85	·048	·240	·03399	·7074	1·245	402·2	707·9	19/18
19/17	46·27	60·33	·056	·280	·04627	·5197	·9147	547·3	963·3	19/17
19/16	60·39	75·06	·064	·320	·06039	·3981	·7007	714·8	1258·0	19/16
19/15	76·50	91·12	·072	·360	·07650	·3143	·5532	905·1	1593·0	19/15
19/14	94·42	108·3	·080	·400	·09442	·2547	·4482	1117·0	1966·0	19/14
19/13	124·9	136·2	·092	·460	·1249	·1926	·3389	1478·0	2601·0	19/13
19/12	159·5	166·4	·104	·520	·1595	·1507	·2653	1888·0	3323·0	19/12
19/11	198·5	199·2	·116	·580	·1985	·1211	·2132	2349·0	4134·0	19/11
19/10	241·7	234·0	·128	·640	·2417	·09949	·1751	2860·0	5034·0	19/10
37/20	37·22	50·47	·036	·252	·03722	·6460	1·137	440·8	775·8	37/20
37/19	45·96	61·07	·040	·280	·04596	·5232	·9208	544·3	957·9	37/19
37/18	66·19	80·91	·048	·336	·06619	·3633	·6394	783·5	1379·0	37/18
37/17	90·06	104·2	·056	·392	·09006	·2670	·4699	1066·0	1877·0	37/17
37/16	117·6	129·6	·064	·448	·1176	·2045	·3599	1393·0	2451·0	37/16
37/15	148·9	157·3	·072	·504	·1489	·1615	·2842	1763·0	3103·0	37/15
37/14	183·8	187·0	·080	·560	·1838	·1309	·2303	2176 0	3830·0	37/14
37/13	243·1	235·2	·092	·644	·2431	·09892	·1741	2878·0	5066·0	37/13
37/12	310·5	287·4	·104	·728	·3105	·07744	·1363	3678·0	6474·0	37/12
61/18	109·1	121·9	·048	·432	·1091	·2204	·3879	1292·0	2274·0	61/18
61/17	148·5	157·0	·056	·504	·1485	·1619	·2850	1758·0	3094·0	61/17
61/16	193·9	195·4	·064	·576	·1939	·1240	·2183	2296·0	4042·0	61/16
61/15	245·5	237·0	·072	·648	·2455	·09795	·1724	2907·0	5116·0	61/15
61/14	302·9	281·6	·080	·720	·3029	·07937	·1397	3589·0	6316·0	61/14
61/13	400·8	354·3	·092	·828	·4008	·06000	·1056	4746·0	8353·0	61/13
61/12	512·0	433·1	·104	·936	·5120	·04697	·08266	6065·0	10674·0	61/12
91/14	451·9	391·0	·080	·880	·4519	·05320	·09364	5365·0	9442·0	91/14
91/13	597·7	491·7	·092	1·012	·5977	·04023	·07080	7080·0	12462·0	91/13
91/12	763·8	600·1	·104	1·144	·7638	·03148	·05541	9048·0	15925·0	91/12
91/11	950·4	719·3	·116	1·276	·9504	·02530	·04453	11256·0	19811·0	91/11

The above resistances and weights of conductors are subject to a variation of 2 per cent.

CHAPTER VI.

VENTILATION.

ONE of the most important of the several operations inseparable from colliery working is that of systematically and continuously ventilating all parts of the mine by sending through the workings, in sufficiently large volumes, currents of fresh, pure air.

In the all-round improvement which has been effected under the head of colliery explosions there are several contributing causes. Improvements in safety lamps, and greater care in their use; the substitution of high-grade explosives for blasting, with stricter regulations and improved appliances for shot-firing—both, no doubt, have done much to reduce the annual death-roll from explosions in mines. But there can be little doubt that the improvements in ventilation, and the very general adoption of mechanical ventilating appliances, have done much more to bring about in this country the present comparative rarity of serious colliery explosions, with their attendant appalling sacrifice of human life.

In these days there can be no possible excuse for defective ventilation in mines. Indeed, as a rule, it may be said that the ventilation of the mine workings in the average British colliery is far more perfect than the ventilation met with in large public buildings.

There is not the slightest difficulty, from an engineering point of view, in providing appliances capable of passing through the mine a million cubic feet of air per minute, should the circumstances demand it. The writer is acquainted with at least one colliery where more than half this volume is circulated through the mine, and many others where the volume is more than a quarter of a million cubic feet per minute.

The ventilation of the modern British colliery presents an interesting subject for those interested in statistics. Taking the average ventilation in the proportion of 100 cubic feet per minute for each day per ton in the output—that is, if a colliery has an output of 2000 tons per day, the ventilating volume will probably be 200,000 cubic feet per minute,—we find that as the ventilation is continuous over the whole twenty-four hours, this means practically five tons of air per day for each ton of coal per day.

Reference to the figures relating to the output of British collieries will show that at the present rate the figure is, in round numbers, 1,000,000 tons per working day; and taking five tons of air for each ton of coal equals 5,000,000 tons of air per day of twenty-four hours. The ventilation is practically continuous all the year round, from which we are able to arrive at the astonishing fact that the air circulated through the workings of British collieries in a year amounts to not less than 1,500,000,000 tons.

The provision of adequate ventilation has become necessary, not only for the purpose of rendering harmless the so-called noxious gases met with in the mine, but also for the purpose of lowering the naturally high temperature which prevails in workings at great depths. This question will call for still closer attention in connection with the working and development of deep mines in the immediate future.

QUANTITY OF AIR FOR VENTILATION.

One is sometimes called upon to decide on the quantity of air necessary for the proper ventilation of a mine. Of course each case must be considered on its merits. Some mines are shallow, others deep; in some gas is rarely if ever met with, in others it is never absent; some mines are hot, others comparatively cool.

The necessary volume must therefore, to a great extent, depend on the character of the mine. The estimate may be based either upon the number of men employed, or, better still, upon the output.

On the former basis, a fair provision is from 100 to 500 cubic feet per man per minute, according to the character of the mine.

Based upon the output of coal—which is the better plan, because the bulk of the gas is given off from the freshly-exposed coal surfaces, and it therefore follows that the more coal is worked the more gas will be given off,—we may allow from 50 to 250 cubic feet per minute for each ton in the average daily output.

In either case the character of the mine has to be carefully considered, and it may even be necessary to adopt more liberal figures.

It is no part of our present duty to discuss the arrangements in the mine for the distribution of the ventilation; we are concerned here only with the means for providing that ventilation in ample volume with the highest economy.

FURNACE VENTILATION.

As a means of producing ventilation for collieries, the furnace is, or ought to be, obsolete. It is an old servant, a faithful servant—one which in its day did its duty in the absence of anything better,—but its day is over, and in these days it ought not to be tolerated. It has nothing to commend it; it is limited in capacity for volume; it has anything but a beneficial action upon the ropes, conductors, and other fittings in the shaft; it is by no means free from danger; and last, but not least, the fuel consumption for furnace ventilation is, on the most favourable estimate, ten times as great as the fuel consumption for the same ventilation by mechanical means.

Beyond this it is not proposed to say anything with reference to furnace ventilation; indeed, furnace ventilation can scarcely be considered as coming within the scope of Mechanical Equipment.

Modern colliery ventilation is effected by mechanical means, and the centrifugal ventilator may be regarded as practically the only mechanical contrivance used for the purpose. There are one or two instances where the screw propeller type has been adopted, but these have not met with much approval, and, indeed, scarcely appear to be suited for colliery requirements.

The history of the development and evolution of the modern centrifugal ventilator, interesting as the subject is, must in these pages give place to the consideration of the more recent types now in general use.

There are a variety of types, and where all possess excellent features it is difficult to make a selection which will neither be too large nor yet omit examples worthy of special mention. In all cases the principle is the same—in obedience to the law of centrifugal force the air is drawn in at the centre and thrown out at the circumference of the revolving arrangement. The revolving element is sometimes open, as in the well-known Waddle fan, but more often enclosed in a spiral or other casing provided with an expanding outlet or chimney, as in the Schiele and Walker fans.

Whatever the particular design, however, or the distinctive features of the fan, all should possess in common the feature of mechanical excellence.

The colliery ventilator, as will have been gathered from the opening remarks in this section, has more work to do than any other single appliance at the colliery. Working continuously from the first day of January until the 31st day of December, week-days and holidays, year after year, almost without intermission, except of the briefest kind and at long intervals, the fan must necessarily be perfect in construction from a mechanical point of view. It is by no means an unusual thing to find that the colliery ventilator at a modern colliery deals with from *9000 to 10,000 tons of air per day*, and this day after day, and often year after year, with only the briefest intervals for rest. The welfare and progress of the mine is entirely dependent upon its action, and reliability is of first importance. Other features—high efficiency, silent running, freedom from vibration, moderate size, and ample volume—are all important, and are to be found in most modern mine ventilators; but first and foremost we must have mechanical perfection and immunity from breakdown.

VENTILATING PRESSURE.

At the outset there is one point which the writer finds it necessary to discuss, a point in connection with which he has found that a good deal of misunderstanding often exists; it is the question of ventilating pressure, or water gauge, and the relationship between the water gauge and the volume of air dealt with by a fan. It must be distinctly understood that the water gauge is a condition imposed by the mine, and that whether a certain fan can pass a required volume of air through

the mine at a given water gauge depends upon the mine, upon the airways, and not entirely upon the fan. Disputes have often arisen between the fan maker and the colliery engineer, because the latter has specified a fan to give, say, 200,000 cubic feet per minute at 4-inch water gauge, and the fan, when erected, has given the required or specified water gauge, but not the volume. The colliery engineer has blamed the fan and the fan maker. It has not occurred to him that his mine is at fault; that, as a matter of fact, his airways *will not pass the quantity specified at the pressure named;* they are too small; there is too much frictional resistance. If the fan sets up the required water gauge, but the mine will not allow the air to pass, that is clearly not the fault of the fan.

For the same reason all comparisons between fans working at different collieries are useless. A fan at one colliery may give certain results, and the *same fan and engine* erected and set to work at another colliery *would probably give entirely different results*, possibly very much better, or it may be considerably worse.

Another extraordinary mistake, often made, is the idea that a high water gauge is an advantage; of course, exactly the reverse is really the case. The writer was brought into connection with a case some little time ago in which the colliery engineer had drawn up the specification for a fan to ventilate a colliery which had hitherto depended upon a furnace for its ventilation. The volume required and specified was only about 60,000 cubic feet per minute, but it was also specified that the fan must deliver this volume at 4-inch water gauge.

The only reason which could be given for this extraordinary stipulation was that they wanted to be on the right side. As a matter of fact, they would have been very much on the wrong side. In practical colliery engineering it is wise to make liberal allowances, but these allowances must be made intelligently and founded on correct principles. In the twentieth century there is no place for the "rule-o'-thumb" mechanic and the "rack-o'th'-eye" engineer. Only too long has that principle prevailed in which, when estimating the power required for any operation, the mode of procedure was to make a guess, multiply by two, and add 50 per cent. The plan may work out all right when the initial guess is fairly correct, but

if, as in the case in point, that guess was unfortunate, the results are not likely to be successful. A considerable amount of argument failed to convince the engineer in this case, and the fan makers were actually preparing to provide an obstruction in the fan drift in order to set up a 4-inch water gauge artificially. Better counsel at length prevailed, and the engineer gave way; the construction and erection of the fan were proceeded with, and when last we saw it the water gauge was barely one inch, although the volume passing through the mine was 90,000 cubic feet per minute.

Generally speaking, the conditions of the mine airways in British collieries are much better than on the continent, where ventilating pressures of six and eight inches, and even higher still, are not uncommon. These high pressures are rarely met with in British collieries, except where unusual circumstances exist, or where an immense volume of air, amounting to half a million cubic feet per minute, or more, has to be dealt with. This subject is further discussed a little later in this section. For the moment the following figures may be useful as showing the actual relationship between volume and pressure in a number of collieries which have come under our own observation :—

Cubic Feet per Minute.	Water Gauge in Inches.
30,000	0·75
48,000	0·8
79,000	1·2
90,000	1·0
101,000	0·9
120,000	1·5
123,000	1·3
140,000	2·0
200,000	2·3
230,000	2·5
230,000	2·9
249,000	3·5
275,000	3·5
300,000	4·0
500,000	6·0

The above are all actual cases, and represent the condition of things at collieries with reasonably good airways and no

A Pair of Vertical Compound Corliss Fan Engines, by Messrs. Walker Brothers, Wigan, H.-P. Cylinder 22 inches Diameter, L.-P. Cylinder 40 inches Diameter, by 8-foot Stroke.

exceptional circumstances. A fair average would appear to be, for a volume not exceeding 100,000 cubic feet per minute, about 1-inch water gauge; from 100,000 to 200,000 cubic feet per minute, from 1 inch to 2½ inches; from 200,000 to 400,000, about 2½ inches to 5 inches.

If it is found, then, in the ventilation of a colliery, that the ventilating pressure required in proportion to the volume is considerably in excess of the figures given above, it either indicates poor airways or exceptional circumstances, such as very long airways to ventilate remote workings.

FAN ENGINES.

The more general introduction of electrical power plant into collieries will result in the application very largely, in the future, of electrical driving of the fan. The arrangement is extremely simple, and means the direct coupling of motor and fan. Both are appliances having a simple rotary motion; both may and generally do run at a fairly high speed, so that the direct coupling of fan and motor will mean a considerable saving in the cost of plant, as well as the cost of large engine houses and foundations.

Where, however, it may be preferred to adopt a steam engine for the fan, that engine should be of the most economical type procurable. The fan engine is called upon to work under conditions which are in every way most favourable for economical working—namely, continuous running under a steady and almost unvarying load. The compound condensing engine has been very largely adopted for the purpose, directly coupled to the large-sized, slow-running fans, or with belt or rope drive for the smaller fans running at higher speeds.

Latterly the development of the high-speed engine, so largely adopted in electrical generating plant, has placed another type of steam engine at the disposal of the colliery engineer for fan driving, and there is no reason whatever why engines of, say, the Belliss type, or the Galloway engine, already referred to, should not be applied, direct coupled to the fan, for colliery ventilation. The practical tests, under trying conditions, which these engines have successfully withstood, working for many years unceasingly, amply testify to their reliability for the purpose suggested. The advantages are—

smaller and less costly fans and engines, the absence of belt or rope drives with their attendant disadvantages, and less expenditure in foundations and engine houses.

ROPE DRIVE FOR FANS.

Where the fan is not direct-coupled the belt or rope drive must be adopted. Messrs. F. Reddaway & Co., of Pendleton, Manchester, make an excellent belting for this purpose, for which is claimed greater durability and reliability than leather belting, as well as the possibility of procuring any length in one continuous piece, thus avoiding numerous joints, each a source of weakness and possible cause of breakdown.

For a rope drive grooved pulleys are of course employed, the number of grooves and the size of the ropes, which are made of cotton, depending upon the horse power to be transmitted from the engine to the fan. It is, however, not advisable to employ ropes larger than 1¾ inch diameter, and it is better to use a larger number of small ropes than a smaller number of large ropes. The small pulley should not be less than thirty times the diameter of the ropes to be used, and the lower side should be the driving side; that is, the lower side should travel from the underside of the fan pulley to the engine pulley.

The power absorbed in rope gearing is about 7 per cent, or, say, 90 to 94 per cent efficiency. The power transmitted depends upon the speed of the rope, and experts who have carefully gone into the subject state that the best results are obtained when the rope speed is 4800 feet per minute. The following figures may be useful:—

Speed of rope.	Diameter of rope in inches				
Feet per min.	1 inch.	1¼ inch.	1½ inch.	1¾ inch.	
2400 ...	10·6 ...	16·6 ...	23·9 ...	32·6	horse power per rope.
3600 ...	14·1 ...	22·1 ...	31·8 ...	43·3	do. do.
4800 ...	15·4 ...	24·2 ...	34·7 ...	47·3	do. do.

It is usual to provide two or three ropes more than may be shown necessary from the above table, to allow for the possibility of defects developing in any of them, a very rare occurrence with good ropes; the fan need not then be stopped whilst waiting for a new rope to be obtained.

The fan should be situated as near to the upcast shaft as may be convenient, always having regard to its being free from risk of damage in the event of an explosion, and connected with it by means of a properly-constructed fan drift amply large for the volume to be dealt with; it should, indeed, have an effective area practically equal to that of the shaft itself.

TO CALCULATE THE SIZE OF FAN ENGINES.

An example, showing how to arrive, approximately, at the size of the fan engine, may be useful at this point. It is necessary that we should know the volume of air to be dealt with, and the probable water gauge which will have to be set up to pass this volume through the mine. Assume a case in which the volume is 300,000 cubic feet per minute, and the water gauge four inches. First calculate the horse power in the air—$300{,}000 \times 4 \times 5{\cdot}2$, and divide by 33,000, equals 189 horse power. Although no doubt the actual results will be better, we shall only assume a combined efficiency for the fan and engine, including the efficiency of the rope drive, of 50 per cent; that is, we shall provide an engine capable of developing 378 indicated horse power.

We will assume a compound condensing engine, with steam at 120 pounds at the boilers, say 110 at the engines, plus 15 pounds atmospheric pressure, equals 125 pounds absolute. The work will be equally apportioned between each of the two cylinders, the high and the low pressure, and we shall cut off at quarter stroke in each cylinder. Piston speed, 400 feet per minute.

We now require to calculate the average effective pressure in the horse power cylinder. For our purpose it will be sufficiently accurate if we apply Boyle's law, and ascertain the pressure at the commencement and at the end of each quarter of the stroke, find the average in each quarter, and finally the average throughout the stroke.

At the commencement of the stroke the absolute pressure is 125 pounds per square inch, which is maintained until the point of cut off, quarter stroke, is reached; the average pressure, therefore, during the first quarter stroke is 125 pounds. In the second quarter we start with 125, and finish with $125 \div 2$, equals $62{\cdot}5$, and the average during the second quarter is therefore $93{\cdot}7$ pounds. The third quarter commences with $62{\cdot}5$, and finishes with

125 ÷ 3, or 41·6, giving an average of 52 during the third quarter of the stroke. In the last quarter we commence with 41·6, and finish with 125 ÷ 4, or 31·25, giving an average of 36·42 lbs. per square inch.

Now add these averages together: 125 + 93·75 + 52 + 36·42 equals 307·17, and divide by 4, equals 76·79, from which we must deduct the back pressure—that is, the final pressure at the end of the stroke,—which was 31·25, leaving 45·54, say 45 pounds per square inch, the average *effective* pressure in the high-pressure cylinder. In this cylinder we are to develop one-half of the total energy required, or 6,240,000 foot pounds per minute. $\frac{6,240,000}{400 \times 45} = 346 \cdot 6$ square inches area of the high-pressure cylinder; that is, the foot pounds per minute divided by the product of the piston speed in feet per minute and the average effective pressure. The high-pressure cylinder will therefore be about 21 inches in diameter.

Proceeding on the same lines with the low-pressure cylinder, and assuming the same ratio of expansion, we shall find that cutting off at one-fourth of the stroke in both cases requires the low-pressure cylinder to be four times the area (twice the diameter) of the high pressure, or, say, 42 inches diameter. The stroke would be about 4 feet.

Fig. 140 gives an excellent idea of a fan engine such as we have in mind in making the above calculation. The photograph did not come into the writer's possession until long after the calculation had been made, and it is interesting to note that the dimensions, as supplied by Messrs. Walker Brothers, agree very closely with those arrived at in the calculation—namely, high-pressure cylinder, 21 inches diameter; low-pressure, 38 inches diameter; stroke, 4 feet. It represents one of Messrs. Walker Brothers' high-class fan engines, for which they have long been famous, a horizontal cross compound condensing engine, with Corliss valve gear, and speed governor. The condenser (surface type) and the air and circulating pumps are not shown in the photograph.

The prevailing custom in this country is to apply the fan as an exhausting ventilator, drawing air through the mine by producing a lower atmospheric pressure than would obtain in the event of the fan being stopped. There is no particular reason

why the fan should be so applied, as against the alternative of blowing air down the downcast shaft and through the workings

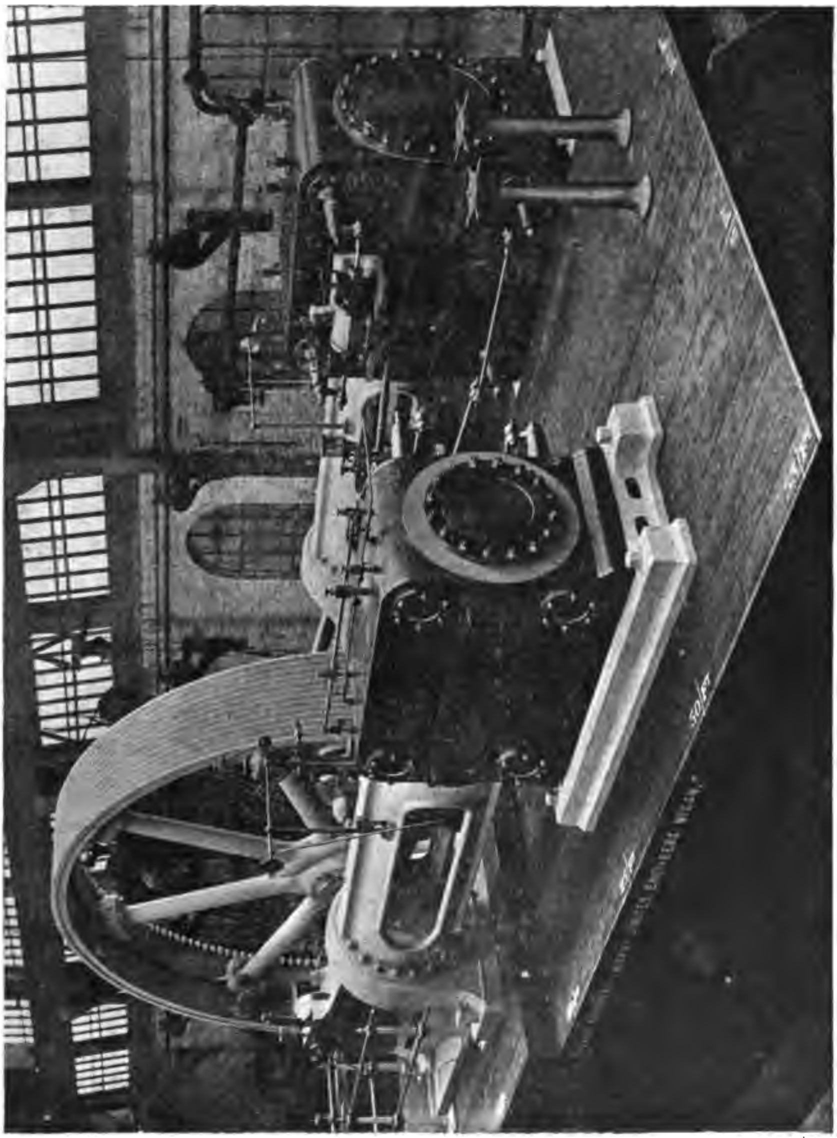


Fig. 140.
A Horizontal Compound Condensing Corliss Fan Engine, by Messrs. Walker Brothers, Wigan.

under a slightly higher pressure than would otherwise prevail. The fan followed the furnace, which had always been applied to

the upcast, and it probably seemed more natural to apply the fan to the upcast. It is conceivable that conditions might arise which would make it more convenient to apply the fan for sending air into the mine; there is no reason why this should not be done.

Where possible it is usual to devote the upcast or fan pit to ventilation, and for the accommodation of pipes for compressed air, delivery pipes from pumps, and electrical cables, etc., the winding being carried on exclusively in the downcast pit.

Not infrequently, however, both shafts are required for winding, in which case special provision has to be made at the top of the upcast, which ordinarily would be closed.

Several arrangements have been adopted, the idea, of course, in each case being the same—namely, to prevent the fan drawing air directly from the outer atmosphere whilst the cage is at the surface. Some form of covering or enclosure must be provided, with a hole, or rather two holes, to accommodate the winding ropes; and this covering is removed or raised by the ascending cage on its reaching the bank level. Then it is, if the arrangements are not well carried out, that a large amount of leakage takes place, throwing an extra load upon the fan engine, and robbing the mine of air. In one arrangement a sort of extinguisher is provided for each side of the pit, two rectangular openings being made, one for each cage, and each being closed by one of the extinguishers; a hole in the centre of each provides for the winding rope, and it is usual to have a small portion in the centre of each extinguisher loose, so that when the cage nears the surface this is lifted first by the cage chains, and the rest of the arrangement is lifted by the cage itself. The cages are specially constructed with sheet-iron sides, and fit the opening so as to leave very little space for air leakage.

This is, perhaps, not a very good arrangement; it is possible for the loose central portion to be drawn up by the rope in the course of a wind, and being drawn into the pulley may throw the rope off, and the result would be serious. Where the extinguisher arrangement is adopted it should not have the loose centre, and the cage on nearing the surface should be so reduced in speed that the cover or extinguisher is raised gently, without suddenly colliding with it in a manner which would be injurious for the rope.

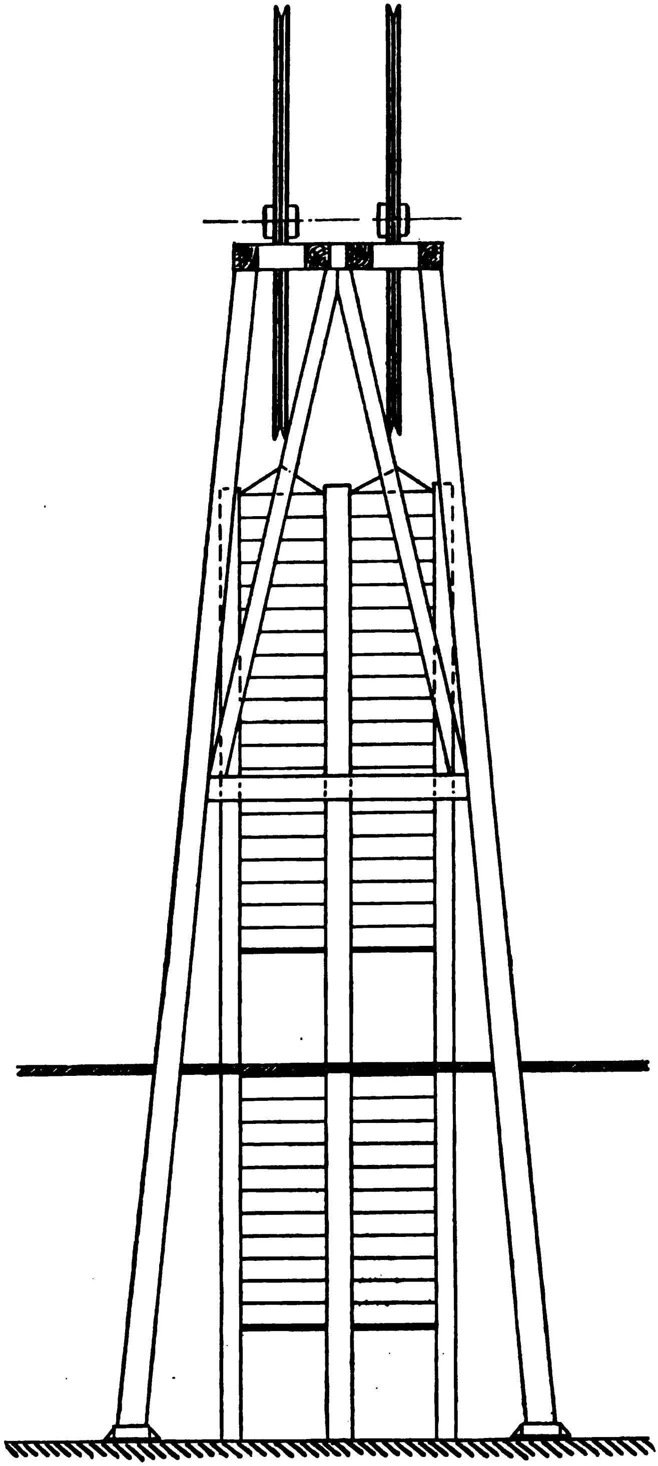
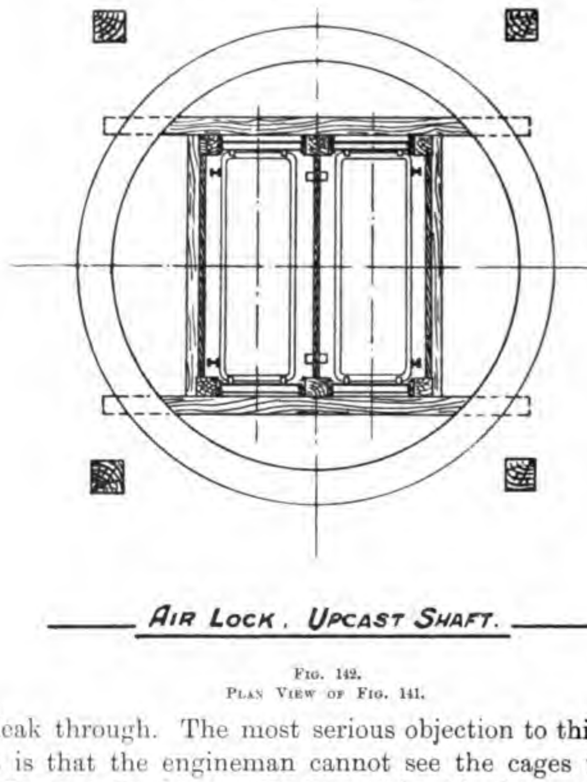


Fig. 141.
Showing Covering of the Upcast Shaft.

A very popular arrangement is one in which a tall wooden tower is erected over the mouth of the shaft, reaching up to the pulleys in the headgear. (*See fig.* 141, *page* 271, *and figs.* 142 and 143.) This tower is constructed of tongued-and-grooved boards (sometimes sheet iron is employed), and made as tight as possible, and is provided with sliding doors with balance weights, which are lifted by the cage on reaching the pit bank level. Here, again, the cage exactly fits the opening, and having sheet-iron sides little air



AIR LOCK. UPCAST SHAFT.

FIG. 142.
PLAN VIEW OF FIG. 141.

can leak through. The most serious objection to this arrangement is that the engineman cannot see the cages until they actually open the doors. Perhaps this objection appears to be more serious than it really is; we are acquainted with a number of collieries where this arrangement is in use, and cannot remember its having been the direct cause of an accident.

A more perfect arrangement, although, no doubt, more costly, and not always possible, is that of constructing a chamber entirely enclosing the pit bank round the mouth of the shaft, and carried right up to the front of the engine house,

so that the engineman has a clear and unobstructed view of all that is going on. The chamber must, of course, be well lighted with windows of strong glass, and entrance or exit is effected by means of an air lock, which is merely a short passage with

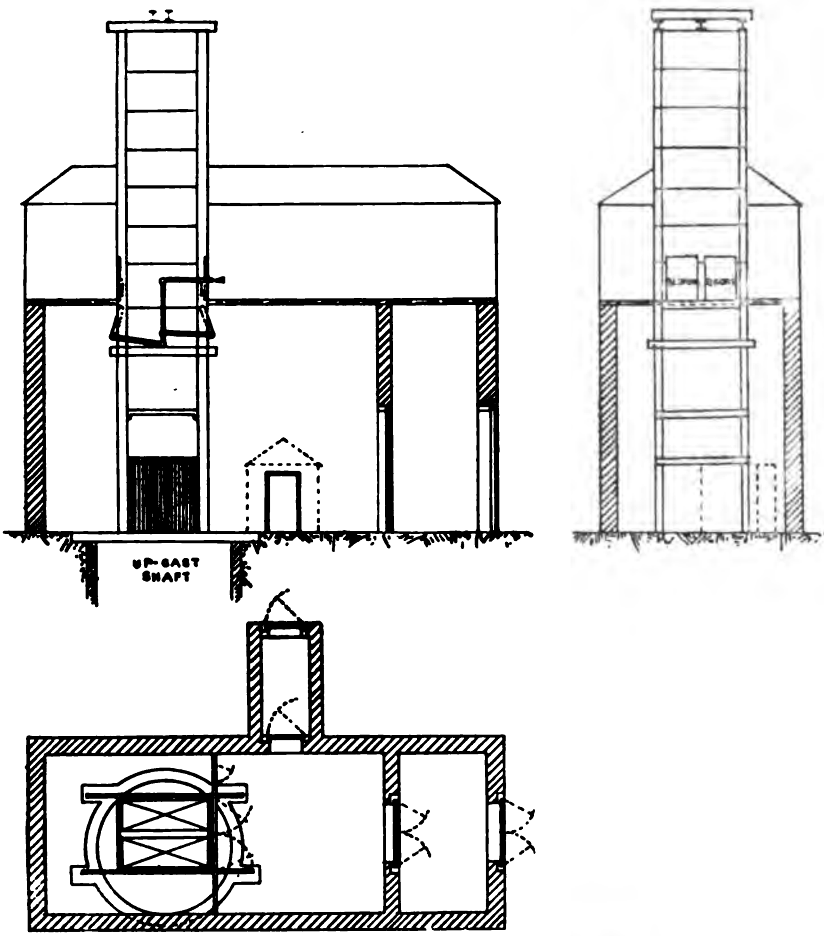


FIG. 148
ARRANGEMENT OF AIR LOCKS AND COVERING FOR FAN PIT.

two doors, opening against the pressure, like the separation doors in the roadway underground connecting the two shafts.

TYPES OF FANS.

No useful purpose will be served by referring to obsolete

types of fans and ventilating machines, and it will be impossible to describe all the various makes of modern colliery ventilators.

Nearly all the large engineering firms who specialise in colliery appliances make a fan of one kind or another, to which they give their own or some distinctive name. These are for the greater part, no doubt, excellent appliances, and accomplish nearly all, if not all, that is claimed for them, but there is not a wide difference in general principle. Colliery fans may conveniently be classed as open-running fans, and fans working in casings. In the first-named division, the Waddle fan, made by the Waddle Patent Fan and Engineering Company, Llanmore Works, Llanelly, is well in the forefront. Indeed, it is perhaps the only example of the open-running type which is in use to any extent, having outrivalled all its competitors.

THE WADDLE FAN.

As a high-class colliery ventilator, the Waddle fan has had a long and honourable career, and the improvements and modifications which have been effected by its makers would appear to indicate that its career of usefulness is by no means approaching finality.

Whatever views one may hold or express as between open-running and closed-running fans, it has never been possible at any time to say that the Waddle fan did not possess that most important feature in a colliery ventilator—reliability. A trifling gain in efficiency here or there is as nothing in a colliery ventilator in comparison with excellence of construction, reliability, and freedom from breakdown. This latter virtue the Waddle fan has always exhibited; recent developments have considerably improved its efficiency.

When the writer first became acquainted with the Waddle fan, it was made in large sizes, driven by direct coupling to the fan engine. Waddle fans of 40 and 45 feet in diameter were not uncommon, and the writer always held the view that they were somewhat unwieldy in proportion with the volume of air dealt with.

The unwieldiness has been eliminated in the modern improvements, the general principle is the same, and the makers still advocate direct coupling with the engine, a practice with which we entirely agree. (*See fig.* 144.)

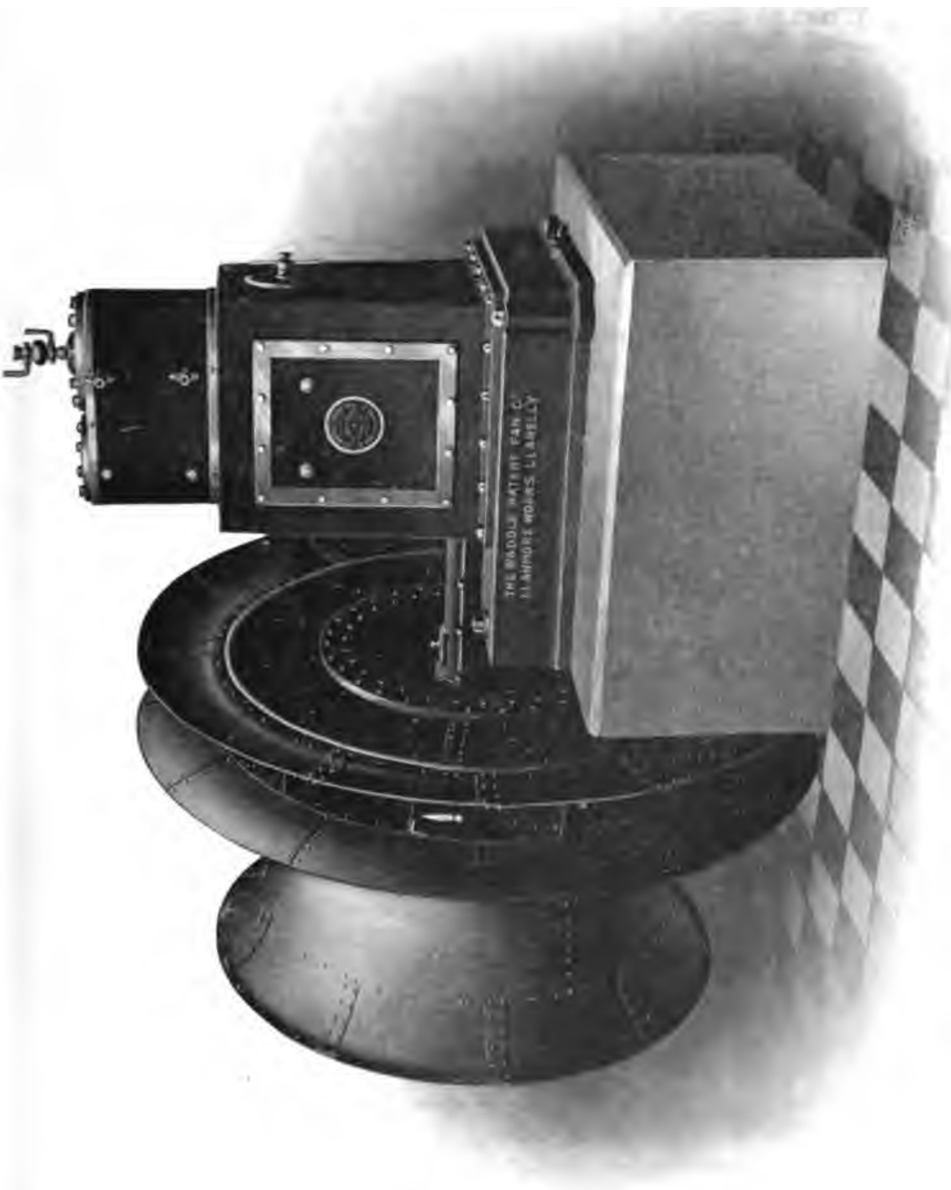


FIG. 144.—A WADDLE FAN, LATEST TYPE, DIRECT-COUPLED TO VERTICAL HIGH-SPEED ENGINE.

The Waddle fan is essentially a single-inlet fan; air is admitted on one side only. The makers claim that this is a distinct advantage, as it affords a simpler and more direct connection with the fan pit. Of course, so far as this goes, almost any make of fan may be arranged as a single inlet, but the writer cannot see that the matter is of vital importance

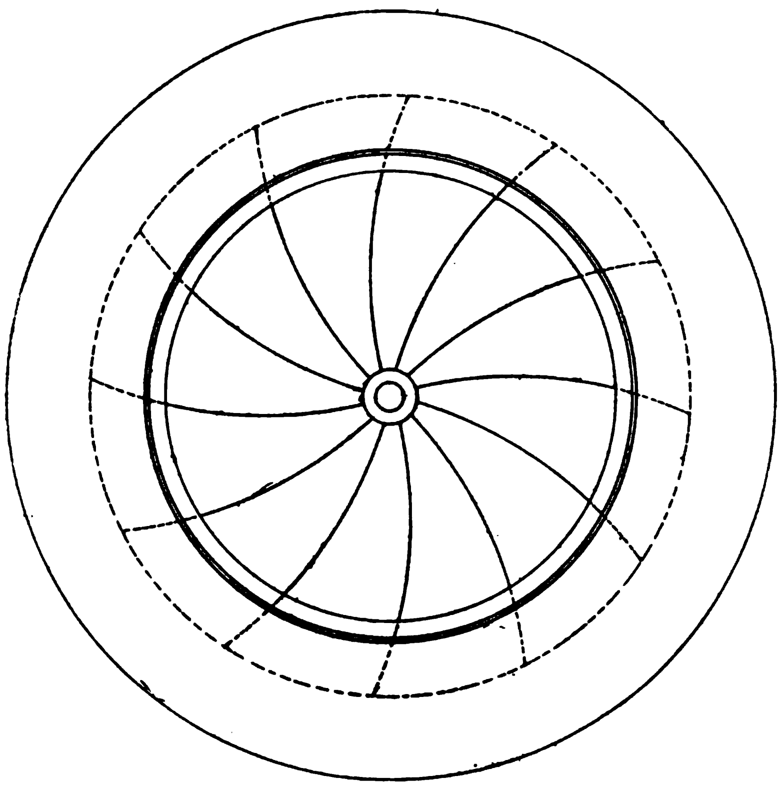


FIG. 145.
THE WADDLE FAN, SHOWING THE BACKWARD-CURVED BLADES.

either way. In construction, the fan may be described as a hollow disc built up of two circular plates, in the centre of one of which is the circular opening or inlet. The space between the two sides or plates is occupied by the blades, which, as a matter of fact, serve to connect the two sides together, being secured to both by angle iron. (*See fig.* 145.) The inlet side of the

fan is not flat, but is shaped like a very squat cone; in other words, the distance between the two sides near the circumference is less than at the inlet (fig. 146), the idea being to provide a uniform area of passage from the centre to the circumference.

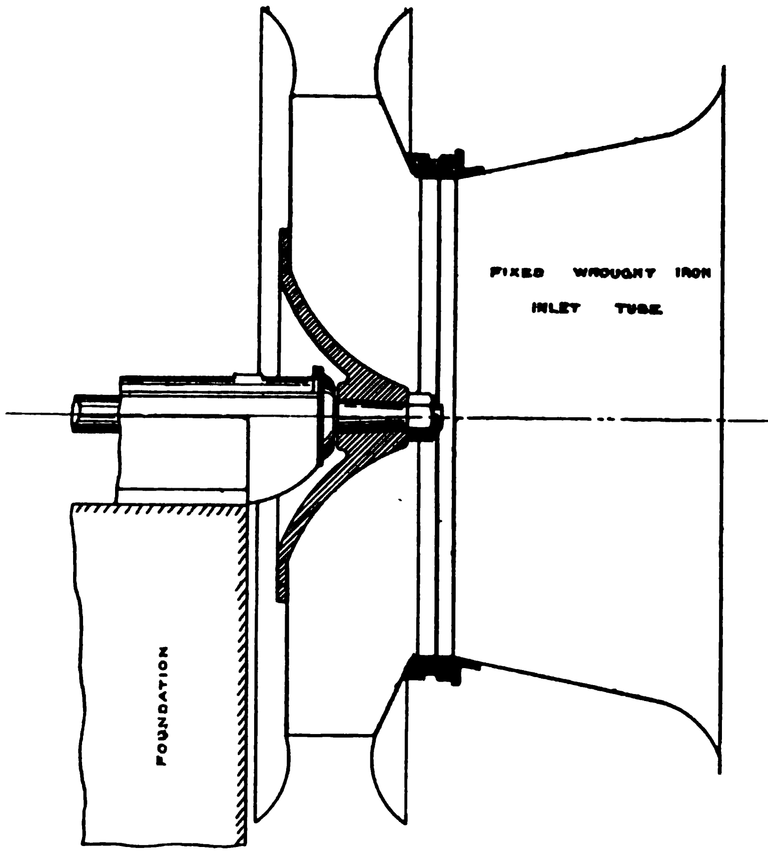


FIG. 146.
SECTION OF THE NEW WADDLE FAN.

The air is discharged freely all round the circumference, and vibration is entirely absent. In the older form of Waddle fan the tips of the blades came right to the circumference; in the later forms the efficiency of the fan has been improved by adding to the circumference of the sides the dish-shaped rims (*see figs.* 144 *and* 147, *pages* 275 *and* 278)—saucer-shaped would perhaps be a more correct description—with the effect of lowering the final velocity of discharge of the air.

In place of the large fans formerly made, the Waddle Patent Fan and Engineering Company now specify the following standard sizes, namely :—

Diameter of Fan in Feet.	Volume in Cubic Feet per Minute.
6	50,000
9	90,000
12	145,000
15	180,000
18	250,000
21	320,000
25	450,000

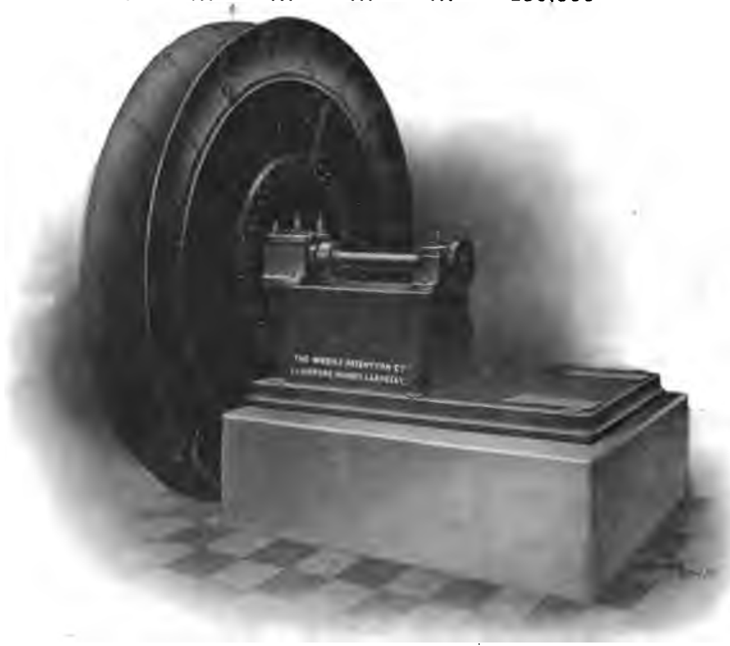


FIG. 147.
A WADDLE FAN, ARRANGED FOR DIRECT COUPLING TO ELECTRIC MOTOR.

An average of a number of carefully-conducted tests, under fair and reasonable conditions, shows a combined efficiency of from 65 to 70 per cent as between the indicated horse power of the engine and the calculated horse power in the air, a result which compares very favourably with other high-class fans of good make.

At the Morfa Colliery, South Wales, a Waddle fan of the

older type, 40 feet in diameter, has been replaced by a modern Waddle of practically half that diameter, 21 feet. At this colliery the conditions necessitate a rather high ventilating pressure, the bulk of the air being taken through one split more than three miles long.

The old fan and engine, whilst doing well up to a certain point, were not doing well enough in the matter of steam consumption. The duty was 61,000 cubic feet per minute, with a 2½-inch water gauge, the fan running at 53 revolutions per minute.

The more modern type of fan, with a more efficient engine, reduced the steam consumption by about one-half, although the volume of air passed through the workings was increased, and a higher water gauge set up.

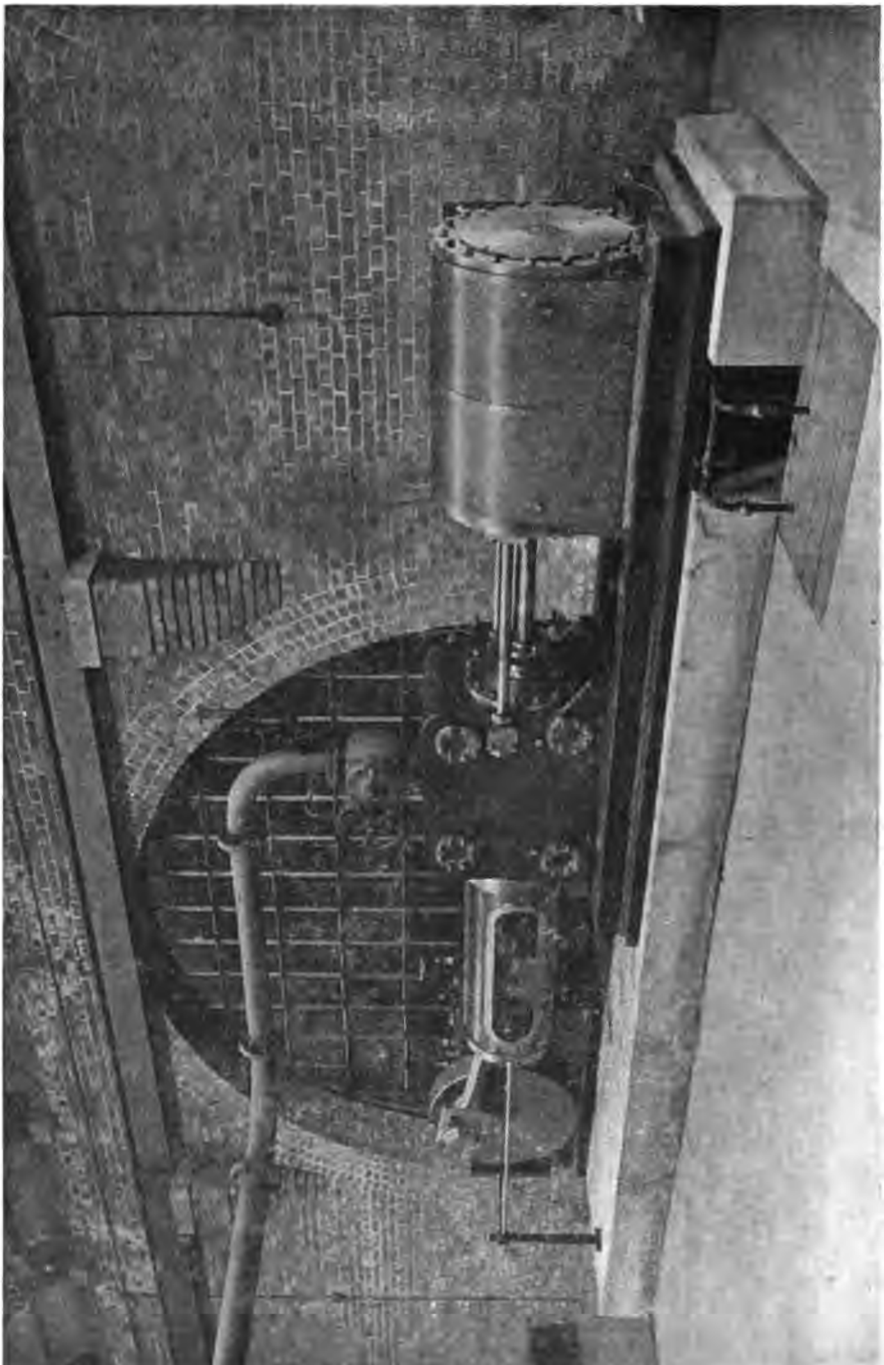
The following figures relate to the working of the new 21-foot fan under the conditions described:—

Revolutions per Minute.	Volume, Cubic Feet per Minute.	Water Gauge in Inches.
136	88,700	5·2
153	97,200	6·2
160	108,500	6·7
168	110,200	7·4

At a colliery near Durham (Houghton Colliery) a 21-foot diameter Waddle fan has replaced a 40-foot Guibal fan. In this instance the conditions prevailing in the mine were more favourable; there is a larger equivalent orifice, and the old Guibal fan, running at 37 revolutions per minute, and setting up a water gauge of 1·2 inches, delivered 201,000 cubic feet per minute.

The new 21-foot Waddle fan, running at 106 revolutions per minute, produced 1·6 inch water gauge, and discharged 272,000 cubic feet per minute, and 303,000 cubic feet per minute at 116 revolutions per minute, and 2·2-inch water gauge.

A large Waddle fan of the improved type at the Cambrian Collieries, Clydach Vale, measuring 35 feet in diameter, direct-coupled to a tandem compound engine, with cylinders 22 inches and 36 inches diameter by 36-inch stroke, is dealing with rather more than 400,000 cubic feet per minute, with a ventilating pressure of 4½-inch water gauge.



A Large Waddle Fan, Latest Type.

As we have pointed out elsewhere, no satisfaction can be given, so far as a useful comparison is concerned, by comparing the work of one particular type of fan at one colliery with another make working at another colliery. The Waddle Patent Fan and Engineering Company have had some careful tests made of their self-contained fans and engines, the inlet of the fan being so arranged that the area of opening could be adjusted to represent varying conditions; that is, they have applied practically the equivalent orifice. The results are given in the following table, from which it will be seen that a useful effect of as high as 80·3 per cent was obtained as between the indicated horse power of the engine and the calculated horse power in the air.

SIX-FOOT SELF-CONTAINED FAN WITH NINE-INCH BY SEVEN-INCH ENGINE.

Equivalent Orifice.	Revolutions.	Volume.	Water Gauge.	Mean Pressure.	I.H.P.	Air H.P.	Useful Effect.
8 square feet...	380	34,013	2·7	22 5	19	14·5	78·4
13 " ...	355	51,623	2·1	27	21·3	17·1	80·3
21·5 " ...	364	69,886	1·45	32·3	26·1	16	61·3
Air admitted freely... ...	354	91,497	—	—	—	—	—

We believe these figures to be perfectly reliable, so far as they go, but we should like to see the tests carried further. The performance represented by the first test, for instance, is very creditable, so far as the fan is concerned, but there would be something radically wrong with a mine which had an equivalent orifice of 8 square feet, and required a ventilating pressure of 2·7-inch water gauge to pass 35,000 cubic feet per minute; the odd ·7 should be more than enough to pass 35,000 cubic feet per minute through a mine with airways worthy of the name. It will be noticed, as bearing out this contention, that with an equivalent orifice two and a half times as large (the third test), the volume delivered was practically twice as great with a slower speed of fan, and a pressure little more than half as much as in the first case. This gives a useful effect of approximately 60 per cent, and we are of opinion that from this to 70 per cent represents the combined or overall efficiency of fan and engine with most of the modern types of

mine ventilators, an efficiency which, as a matter of fact, may be considered very good. It would be interesting to know the efficiency of the fan and engine at the Houghton Colliery, Durham, previously referred to as producing 303,000 cubic feet per minute through the mine, with a ventilating pressure of 2·2-inch water gauge.

The makers of the Waddle fan have recognised that the electric motor will, in the future, be largely applied for actuating mine ventilators, and they have accordingly arranged the fan for direct coupling to an electric motor. (*See fig.* 147, *page* 278.)

THE WALKER FAN.

The closed-running fans, or fans in casings, constitute a more numerous class; they are for the greater part modifica-

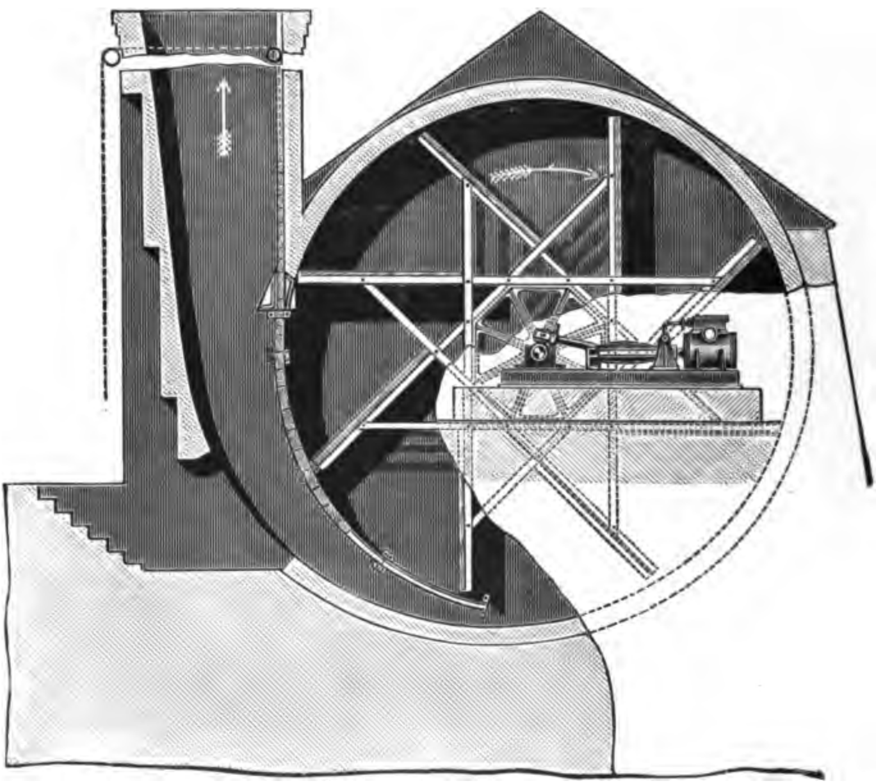


Fig. 148.
The Guibal Fan, Original Type, 30 Feet Diameter by 10 Feet Wide; 125,000 Cubic Feet per Minute at 3-inch Water Guage.

tions and improvements upon the fan of Guibal. (*See figs.* 148 *and* 149.) Most of the fans used in this country have backward-curved blades, or blades with a backward inclination, and the casing is in nearly every instance of the volute or spiral type, which has been established as a more perfect arrangement than the close-fitting casing of the Guibal fan. All, too, have the expanding chimney, where used as exhausting fans, and are either single or double inlet.

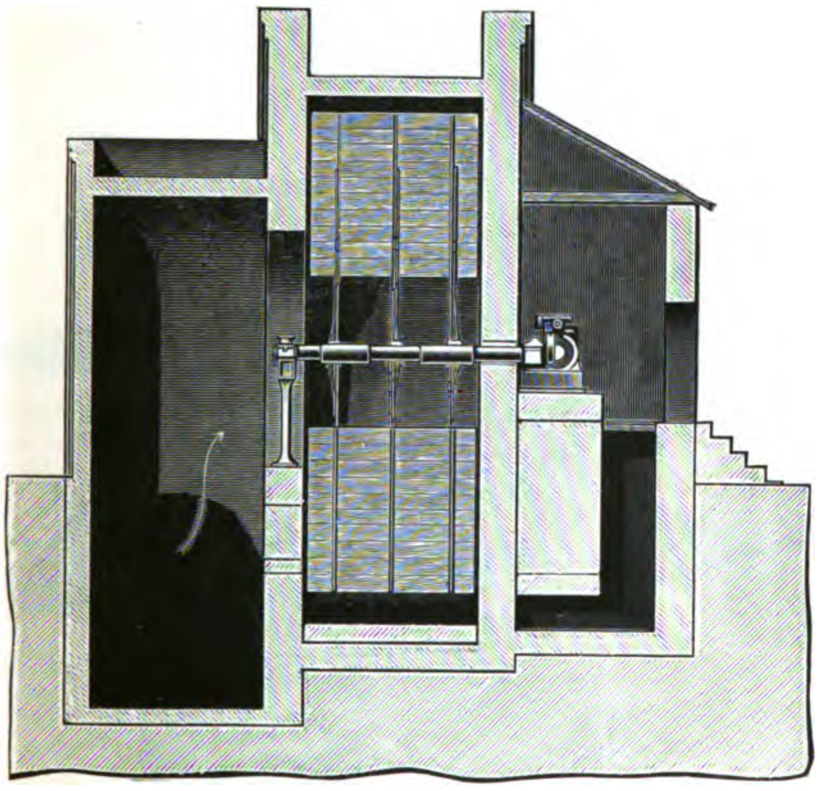


FIG. 149.
GUIBAL FAN, TRANSVERSE SECTION OF FIG. 148.

Some are rather large, and run at a moderate speed; others are smaller, and run at a fairly high speed, and the tendency with modern fans seems to be in this direction.

Perhaps the best known of the moderate-speed type is the "Indestructible" fan, made by Messrs. Walker Brothers, of Wigan.

A large number of these are at work in British collieries, and it is by no means unknown abroad. Wherever it has been installed it appears to have justified its title, and as a colliery ventilator leaves little to be desired. It is practically an improved form of the Guibal fan, upon lines which were strongly advocated by the author before Messrs. Walker Brothers took the matter up.

FIG. 150.
THE BLADES OF THE WALKER INDESTRUCTIBLE FAN.

The revolving portion—the fan proper—consists of a number of blades, shaped as in fig. 150, as a rule eight or ten in number, all curved backward from the direction of rotation. On the fan

shaft are keyed two cast-iron bosses, between which are two steel discs.

The radial arms, which carry the fan blades, are shaped like segments of a circle, and sandwiched in between the discs, and the whole is securely riveted together, except the central portion, between the cast-iron bosses, which is bolted right through. In this way the whole structure is strongly secured. The blades, which spring from the circumference of a small circle near the centre of the fan, are secured to the radial arms by means of angle irons, and in the larger sizes the whole arrangement is further strengthened by means of tie rods.

The anti-vibration shutter is an important feature in the Walker fan. Instead of the division between the fan chamber and the expanding chimney taking the form of a plate with a horizontal edge, the anti-vibration shutter provides a plate with a piece cut out in the form of an inverted V. This avoids the rapid succession of puffs as each blade rushes past the opening into the chimney, a common source of nuisance as well as extra wear and tear in the older forms of fans. For example, assume a fan with ten blades working at 100 revolutions per minute, this means 1000 puffs per minute, setting up a rapid vibration or trembling, which not only shakes the whole machinery but becomes a serious source of annoyance to the neighbourhood for some considerable distance around. The V-shaped opening in the Walker fan presents a gradually narrowing opening to the blades, and there is a shading off, so to speak, of the pressure from each blade, instead of the sudden cutting off provided by the older forms of fans.

Walker fans are generally arranged as double-inlet ventilators; the width is usually about one-third the diameter; each circular inlet is about one-half of the diameter of the fan. (*See figs.* 151 *and* 152, *pages* 286 *and* 287.)

In order to give some idea as to the proportions of these fans with reference to the volume of air they will move under ordinary conditions, the following instances may be given of fans actually at work:—

Volume, Cubic Feet per Minute.	Diameter of Fan.
200,000	20 feet.
240,000	24 „
270,000	24 „
500,000	30 „

In a paper read before the Manchester Geological and Mining Society, by Mr. Charles H. Higson, on the Walker fan and engine at the Park Collieries, Garswood, Lancashire, of which

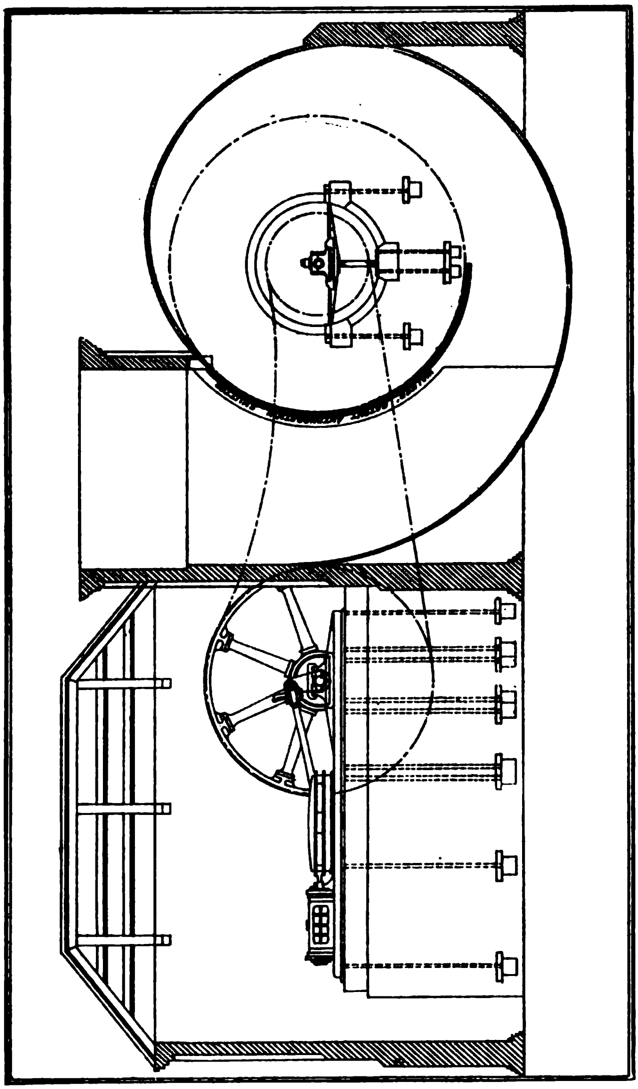


Fig. 151.
Elevation of Walker Fan and Engine.

Mr. Higson was then the manager, he gave some very complete records of an exhaustive series of tests, under working conditions, of the fan and engine carried out under his supervision.

These figures are not only interesting as demonstrating the duty of the fan and engine, they serve also as an excellent example of the manner in which a test of this character should be recorded.

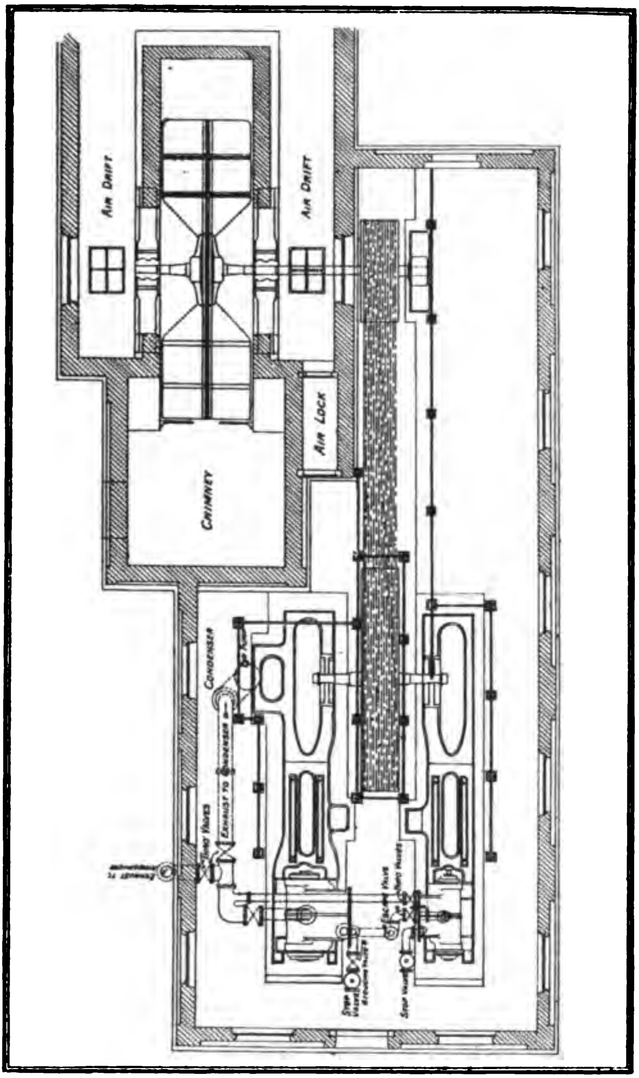


Fig. 152.
Plan of Walker Fan and Engine.

It may be necessary to explain, in reference to the following particulars, the exact meaning of the expression in the fifth line:—"Space swept by blades in cubic feet" with the figure

3619 following. If we calculate the area in square feet of a circle 24 feet in diameter, and multiply by eight feet (the width of the fan), we shall obtain, as a result, 3619 cubic feet, and, according to the figures given, the fan, at each revolution, discharged a volume of air equal to about 65 or 66 per cent of its own capacity.

RECORD OF DUTY OBTAINED FROM A 24 FEET DIAMETER BY 8 FEET WIDE WALKER INDESTRUCTIBLE FAN, DRIVEN BY A TWIN COMPOUND CONDENSING ENGINE, WITH CYLINDERS 22 AND 38 INCHES DIAMETER BY 4-FOOT STROKE :—

	Number of Test.			
	1.	2.	3.	4.
Revolutions per minute of fan	84·6	98·5	110	118
Do. do. of engine	40	46	51·3	56
Volume, cubic feet per minute	201,096	232,073	262,925	286,895
Cubic feet per revolution of fan	2,377	2,356	2,390	2,431
Space swept by blades, cubic ft.	3,619	3,619	3,619	3,619
Volume per cent fan capacity	65·6	65·1	66	67·1
Water gauge at pit top	3 in.	4 in.	5 in.	6 in.
Periphery speed, feet per min.	6,378	7,425	8,292	8,896
Horse power in the air	95·47	146·26	207·15	271·8
Steam pressure, pounds ...	90	87	90	88
Cut off in H.P. cylinder... ...	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$
Vacuum on gauge, inches ...	28	28·25	28	28
I.H.P. of engines	154·7	229·57	322	402·4
Percentage useful effect ...	61·7	63·71	64·3	67·54
Barometer in inches	30·65	30·6	30·6	30·6
External temp. degrees F. ...	44·5	43·5	43	43·5
Temp. in fan drift do. ...	51·0	50·5	50·5	51·0

SIX HOURS' TEST OF FUEL AND STEAM CONSUMPTION.

TWO LANCASHIRE BOILERS, 30 FEET BY 8 FEET.

Speed of fan, revolutions per minute	110
Do. do. peripheral, feet per minute...	8292
Speed of engines, revolutions per minute	51·3
Average steam pressure in engine room	84·4
Coal consumed per hour, pounds	856·3
Water evaporated per hour, pounds	6872·5
Water evaporated per pound of coal	8·02
Coal consumed per H.P. hour in the air	4·13

Steam consumption per I.H.P hour of engine	...	20·7
Coal consumption do. do.	... ...	2·6

THE SCHIELE FAN.

The Schiele fan, made by the Schiele Union Engineering Company, of Manchester, belongs to the high-speed type, and is consequently smaller in proportion to the volume of air dealt with than, say, the Walker fan, last described. It must be understood, however, that the term "high speed" relates to

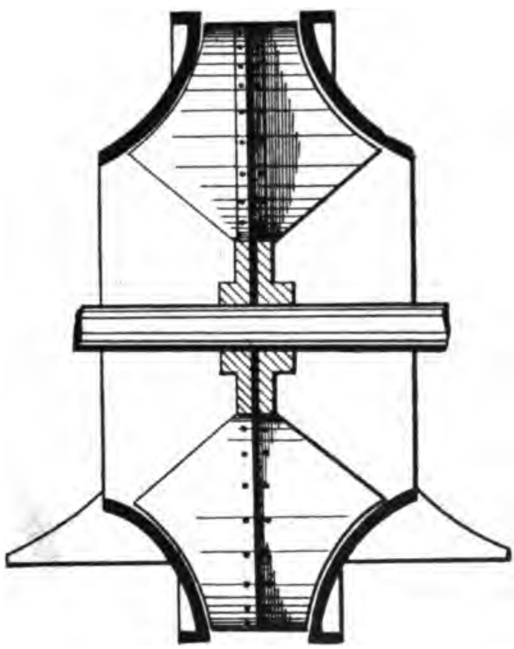


FIG. 153.
CROSS SECTION OF THE SCHIELE FAN.

the number of revolutions per minute, and is, perhaps, rather misleading, because for the same water gauge a large diameter Walker fan, and a small diameter Schiele fan, will have practically the same peripheral velocity, although the latter will revolve more rapidly.

The shape of the Schiele fan blades is well shown in fig. 153. They are curved backward, and revolve in a spiral casing. On either side of the revolving blades are two circular castings,

shaped so as to conform with the curved edges of the blades. These sides form the inlet; the air enters on both sides through the circular openings, and is discharged all round the circumference into the volute casing. Fig. 154 shows a Schiele

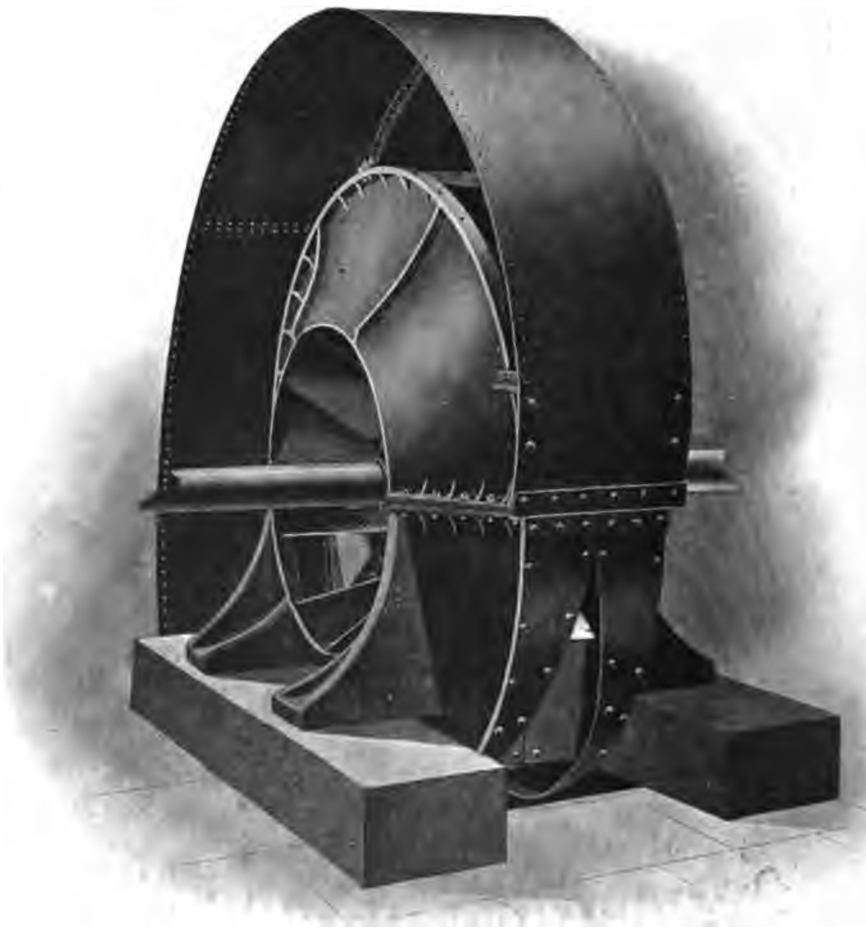


FIG. 154.
SCHIELE FAN IN COURSE OF CONSTRUCTION, WITH WALKER'S ANTI-VIBRATION OR V SHUTTER.

fan in course of erection, fitted with a Walker **V** shutter. The shaped sides surrounding the blades are clearly shown in this illustration.

Being a high-speed fan it is usually driven from the fan

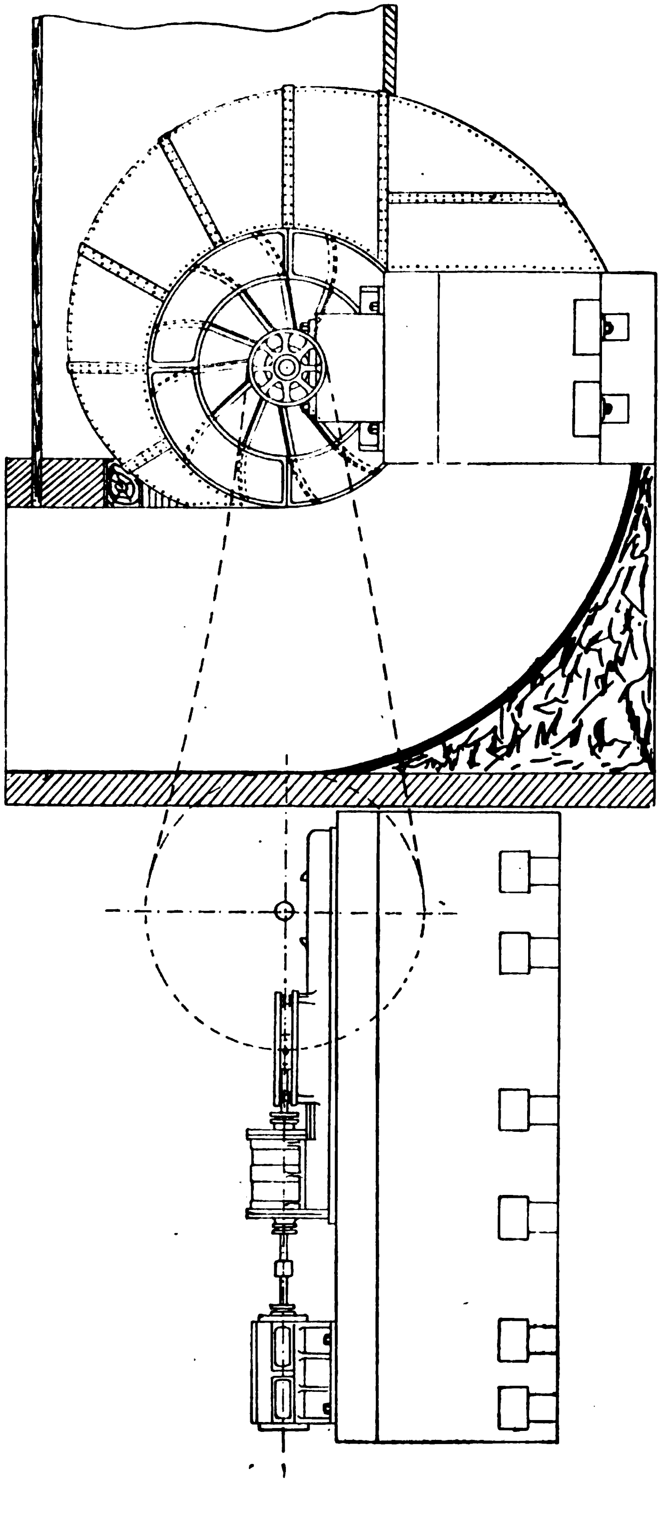


FIG. 155.
SECTIONAL ELEVATION OF THE SCHIELE FAN.

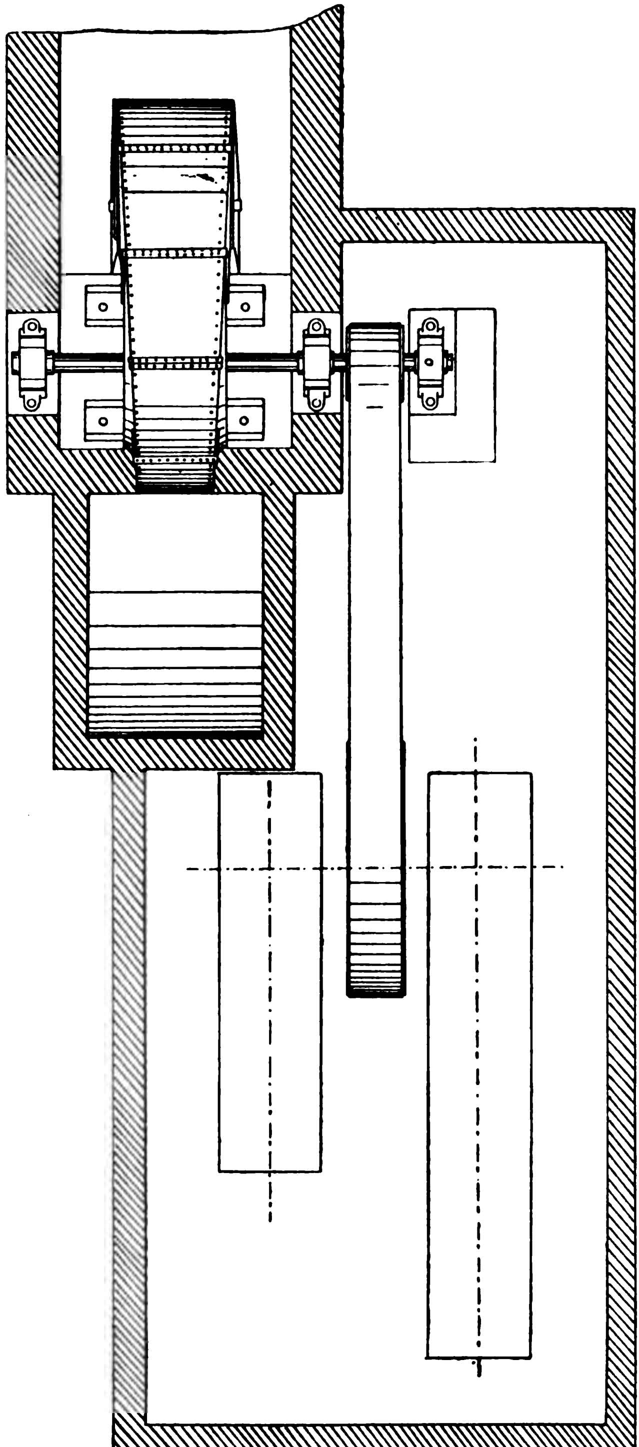


Fig. 158.
Plan of the Schiele Fan.

engine by means of a belt or ropes. With electrical drive it may be direct-coupled.

For purposes of comparison with the sizes of other fans, the following particulars relating to the Schiele fan may be of interest:—

Diameter of Fan.	Cubic Feet per Minute.
8 feet 0 inches	60,000
9 feet 6 inches	100,000
11 feet 0 inches	150,000
12 feet 0 inches	200,000
13 feet 6 inches	230,000
17 feet 6 inches	250,000

The blades are twelve in number, and are secured to a central disc or diaphragm, which is in turn bolted to heavy bosses keyed on to the shaft. The structure is exceptionally strong, and the test of years has shown it to be in every way a thoroughly-reliable and highly-efficient mine ventilator.

Being of comparatively small dimensions in proportion to the volume dealt with, the Schiele fan is less costly in the matter of foundations and excavations, and is to a very great extent self-contained.

Fig. 155 (*see page* 291) and fig. 156 are intended to give an idea of the backward curvature of the blades and the spiral casing.

THE CAPELL FAN.

No attempt has been made to place the fans described in these pages in order of merit, the intention has been rather to select those fans which have, in British collieries, become recognised as standard types. Quite naturally, the respective makers express the opinion that their particular fan possesses features which place it an immeasurable distance above all others. This system of rivalry has a most beneficial effect; each maker constantly strives to attain better results than his competitors, and as a consequence we get more perfect appliances in each case. We are personally acquainted with all the fans we have described and have selected them because each, in its own way, is an appliance possessing features of excellence. Each one is a colliery ventilator, which may, without hesitation, be adopted and installed for the highly important duty of ventilating the mine; a duty which, as we have already remarked, demands mechanical excel-

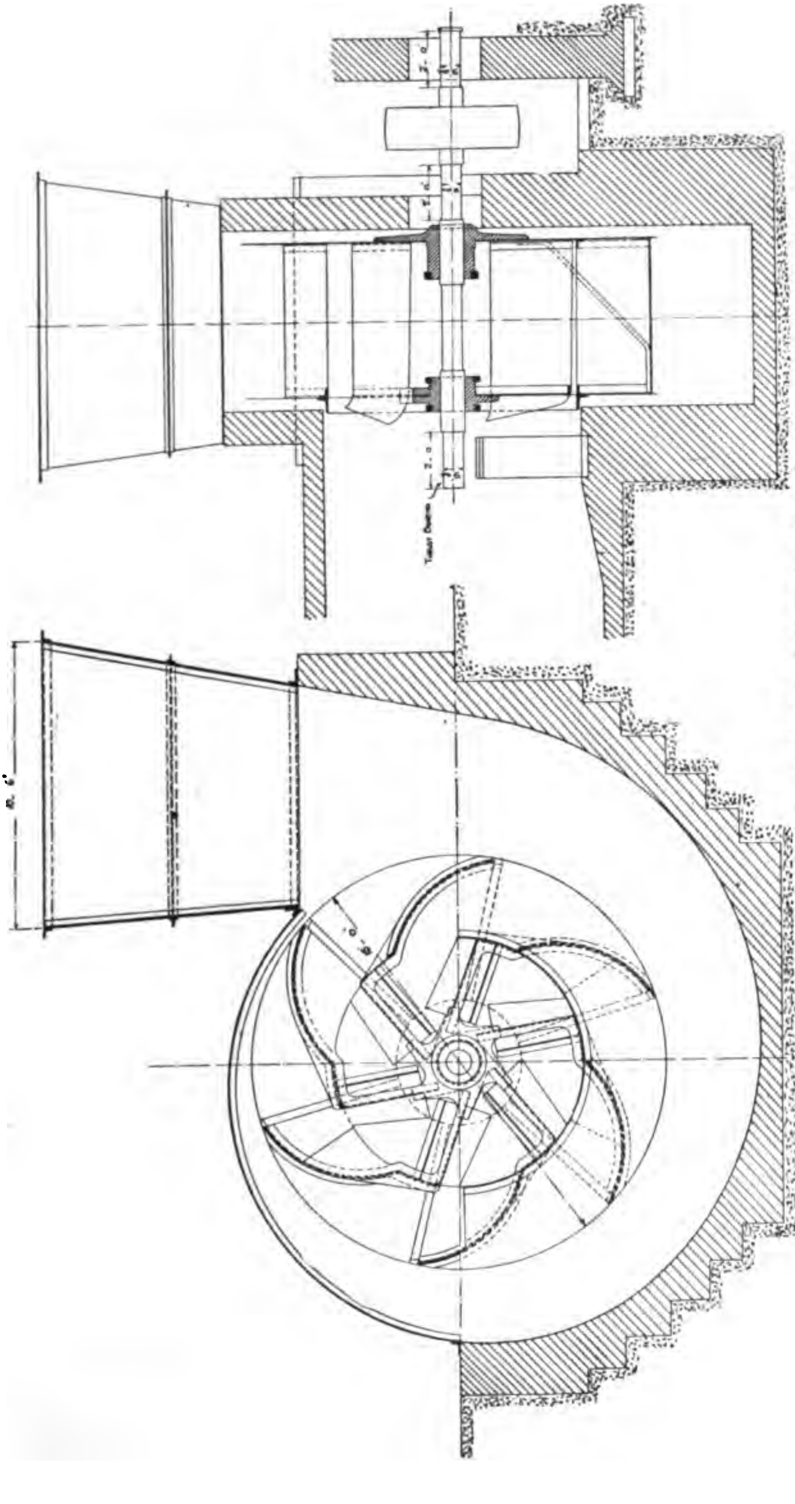
lence, reliability, and a reasonable percentage of useful effect. These qualifications are possessed by all the fans we have illustrated and described in these pages, and the Capell fan exhibits them in no less a degree than the others.

Although of British origin and British manufacture—being constructed in Newcastle-upon-Tyne, by the Capell Fan Company—the Capell fan appears to have attained considerable popularity on the continent, where, as we have remarked elsewhere, the conditions in the mine, as regards ventilation and airways, do not reflect credit upon continental mining practice. For example, the Capell Fan Company furnish particulars of one of their fans at a German colliery, producing 328,000 cubic feet per minute with a *water gauge of 15·8 inches.* This, of course, is an excellent testimonial for the fan; but one would like to know more about the conditions of the mine which render necessary this enormous pressure, over 80 pounds per square foot, in order to pass 328,000 cubic feet per minute. Of course there may be extraordinary conditions prevailing which we are not acquainted with, but if this colliery requires a 15-inch water gauge to ventilate it in the ordinary way, the airways must be more like rat-holes than anything else.

The Capell fan is made in various sizes from 5 feet diameter to 20 feet, capable of dealing with anything up to half a million cubic feet per minute. It excels at high water gauges, which perhaps accounts for its popularity on the continent, where the conditions appear to require a high ventilating pressure. (*See fig.* 158, *page* 296.)

It is made either as a single or double inlet; the latter is twice as wide as the former, and has practically twice the capacity. The double-inlet fan is, indeed, to all intents and purposes, two single-inlet fans combined.

The smaller sizes have six blades, and the larger sizes eight, or, to be strictly accurate, twice the number in each case, because the construction of the Capell fan is such that it has two sets of blades, an inner and an outer set. The revolving portion of the ventilator consists of a drum or cylinder, with one set of blades inside the drum, the other set outside. The outer blades are curved backward, and the inner blades, which are inclined backward, have their radial edges on the inlet side curved forward, somewhat like the blades of a screw-propeller



15'-0" x 5'-6" SINGLE INLET 'CAPELL' FAN.

Fig. 157.
The Capell Fan.

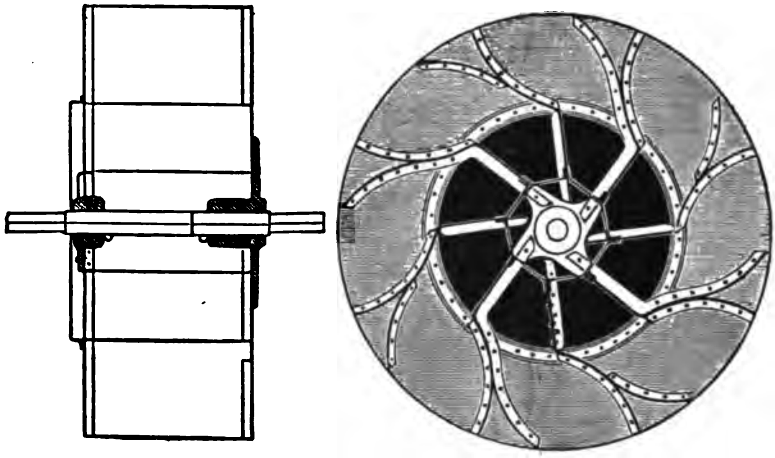


Fig. 158.
Modified Form of Capell Fan for High Water Gauge.

Fig. 159.
A Single-Inlet Capell Fan, Revolving Portion, showing the Screw-Propellor Shape of the Inner Blades at the Inlet.

type of fan, the idea being to gather the air in, so to speak. From the inner blades the air is discharged through openings in the drum or cylinder, where it is further dealt with by the outer blades, which take a very considerable backward curve. The fan revolves in a spiral casing, with an expanding chimney. An inspection of fig. 157 (*see page* 295), and figs. 158 and 159 will help to make the construction and principle of the Capell fan quite clear.

THE SIROCCO FAN.

Although as a colliery ventilator the Sirocco fan is by no means so well known as those previously referred to, we do not hesitate to include it in these pages, being fully convinced that it is destined to become a standard type of mine ventilator.

Many good appliances have suffered, at the commencement of their career, from over-praise. Too much has been claimed for them, and too much is more than sufficient. Level-headed men who have an intelligent appreciation of Newton's "Principle of Work" look with something like suspicion upon appliances for which over 100 per cent useful effect is claimed. More than one inventor has been bold enough in his enthusiasm to make such claims for his invention, and the colliery fan has not escaped the vagaries of inventive eccentricity.

Some years ago, at a meeting of one of the Mining Institutions, a paper was read—by a man who ought to have known better—upon a fan which was claimed to exhibit all the excellent features a fan could possibly possess (and a few which it could not), but none of the vices. So remarkable, indeed, were its capabilities, that the inventor—the reader of the paper—was able to demonstrate mathematically (at least to his own satisfaction) that his fan would give something more than 100 per cent efficiency. The chair was occupied by an eminent engineer, since deceased, who congratulated the inventor upon the success of his fan; he recommended that all collieries should be equipped with several of these fans, and suggested that the winding engines, pumping, haulage, etc., might be operated by the energy *created* by the fans, thus dispensing with costly boilers and steam engines. The inventor did not take kindly to these suggestions; he appeared to think the discussion was becoming tinged with sarcasm.

We do not imply that any such absurd claims have ever been put forward on behalf of the Sirocco fan. As a matter of fact, so far as useful effect is concerned, it appears to equal, but not to excel, the results which have been obtained, under fair conditions, by other fans of good make. In the matter of speed and capacity, however, the Sirocco fan presents some very remarkable features.

The Sirocco fan is made by Messrs. Davidson & Company Limited, of Belfast, and for a long time it was applied exclusively for mechanical draught purposes, in which application it figures extensively in many of the largest steamships, as well as battleships belonging to His Majesty's navy. Indeed, its remarkable properties enabled it to take the place of other fans already installed in many of these vessels. Its makers claim that under similar conditions it will deliver from three to four times as much air as any other type of fan of equal dimensions running at the same speed. For example, at a colliery in the North of England, a Sirocco fan 6 feet 3 inches in diameter is delivering 226,000 cubic feet per minute. At the same colliery are two Guibal fans, one being 30 and the other 36 feet in diameter. These were both connected with the same pit, and were working when the Sirocco fan was erected, so that tests have been made under the only really satisfactory conditions possible—that is, ventilating the same mine.

When the two Guibals are working *together* they deliver a *total* volume of 200,000 cubic feet per minute; when the Sirocco fan is *working alone* it delivers 226,000 cubic feet per minute, or 26,000 cubic feet per minute more than the two large Guibals together, and yet the periphery speed of the former is actually less than the speed of either of the Guibals.

Now these figures are very extraordinary, and they would not find a place in these pages were we not perfectly satisfied as to their accuracy. We have, however, made exhaustive tests with the Sirocco fan, and are amply convinced of its capabilities in this direction. A most remarkable feature is the fact that the air, as it leaves the circumference of the fan, *has a velocity of from 70 to 80 per cent greater than the periphery speed of the fan itself*, which to some extent accounts for the large capacity of this fan. It has been laid down, and generally accepted as

good practice in fan design, that a large inlet is desirable. The inlet of the Sirocco fan is *as large as the fan itself* (fig. 160), a feature not possessed by any other type of fan. The air is discharged into a spiral casing, and finally emerges from an expanding chimney.

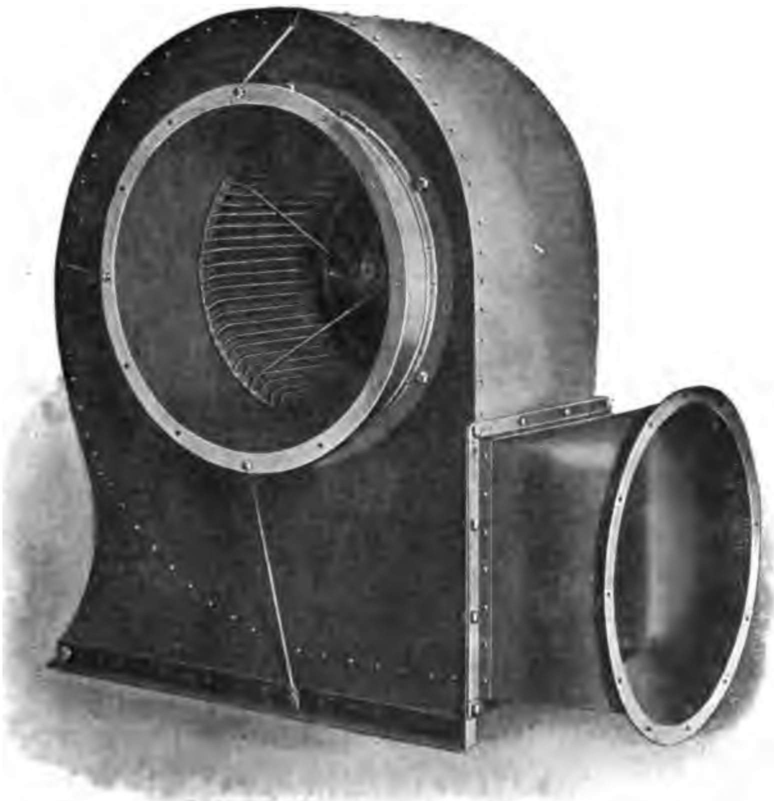


FIG. 160
THE SIROCCO FAN, SHOWING THE LARGE AREA OF INLET.

In principle we believe the Sirocco fan to be correct; in point of mechanical construction there is perhaps room for some little modification in one or two details, which should give it those most essential features of strength, reliability, and freedom from breakdown; indeed, the makers are, at the time of writing, experimenting with a view to constructing a modified form of the fan specially adapted for colliery ventila-

tion, the earlier types not having been designed specially for this purpose. The principle, however, will be the same, and the following description, with the accompanying illustrations, should make this quite clear. (*See fig*. 161.)

In place of the eight or ten large blades usually provided, springing from the centre, the Sirocco fan has 64 blades; but these are very short radially, being only about one-sixteenth of the diameter of the fan. A forward curvature is given to the blades, and, as we have already indicated, the inlet is as large as the fan itself, so the air enters without obstruction of any kind, and there is no churning, or even revolving of the air, until actually taken up by the blades. There is an entire absence of vibration when the fan is working; all that can be

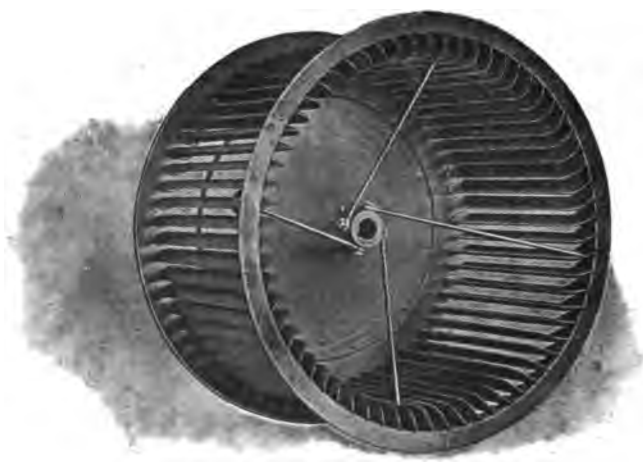


FIG. 161.
THE REVOLVING PORTION OF THE SIROCCO FAN.

heard is the rush of air. In its original form, as applied for mechanical draught purposes, the fan was a single-inlet; for colliery purposes it will probably be applied as a double-inlet. (*See fig*. 162.)

We are not aware that the makers claim for the Sirocco fan a higher useful effect than other good fans, but what they do claim—and there is no doubt the claim can be substantiated—is that for a given volume a much smaller fan, and therefore a much less costly arrangement, is necessary; not only is the fan itself less costly, but the expenditure for excavations,

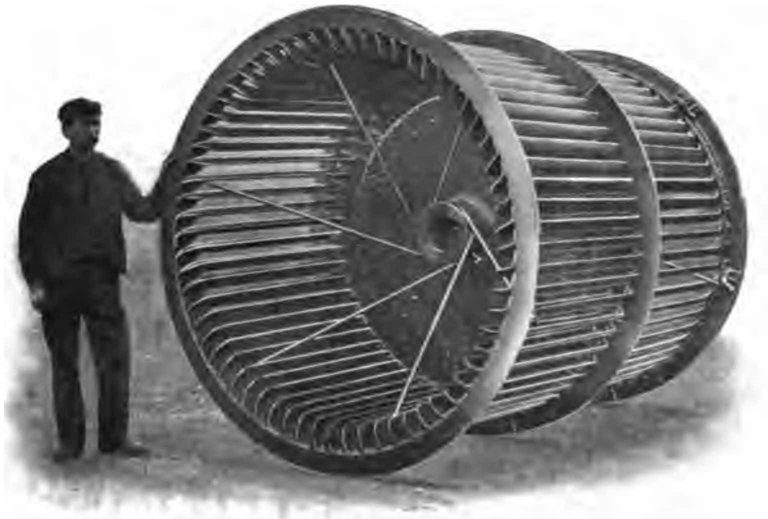


FIG. 162.
A DOUBLE-INLET SIROCCO FAN, REVOLVING PORTION.

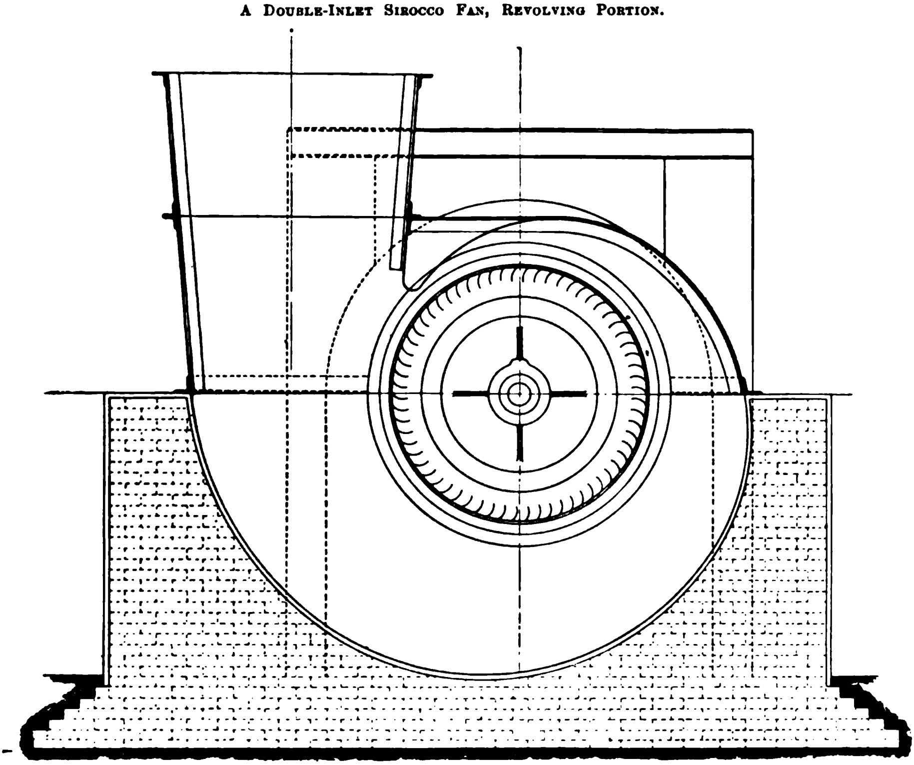


FIG. 163.
SECTIONAL ELEVATION OF THE SIROCCO FAN AT PELTON COLLIERY.

foundations, and engine house is considerably less than would be required with most other types. A remarkable feature is the fact that this fan sets up a higher water gauge than any other fan for the same periphery speed, and, as has been already pointed out, the air leaves the periphery with a velocity much higher than the periphery speed of the fan itself.

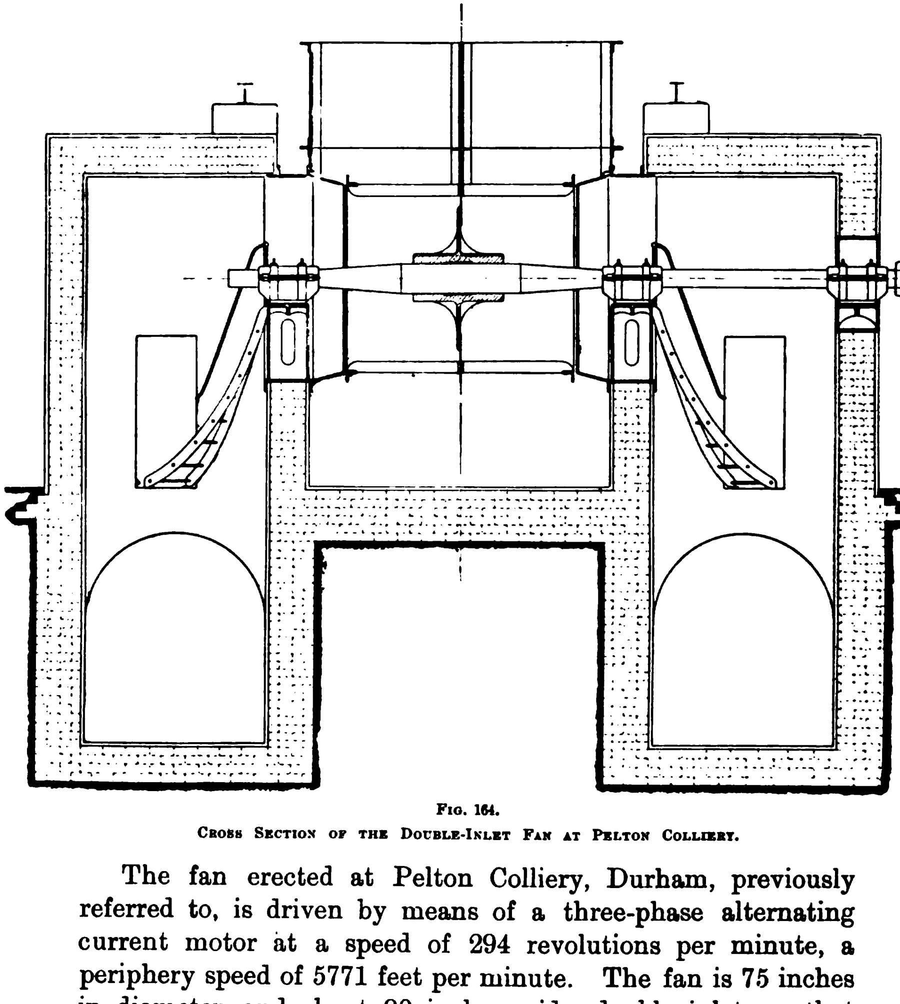


FIG. 164.
CROSS SECTION OF THE DOUBLE-INLET FAN AT PELTON COLLIERY.

The fan erected at Pelton Colliery, Durham, previously referred to, is driven by means of a three-phase alternating current motor at a speed of 294 revolutions per minute, a periphery speed of 5771 feet per minute. The fan is 75 inches in diameter, and about 90 inches wide, double inlet, so that although it is much wider in proportion to its own diameter than other fans, it is really not any wider than other fans would be made for the same volume. (*See fig.* 163, *page* 301.)

At the same colliery there are two Guibal fans; one is 30 feet in diameter, and the other 36 feet. Working together, the former running at 62 and the latter at 52 revolutions per minute, equal to a periphery speed of 5843 and 5880 feet per minute respectively, these two fans set up a water gauge of rather less than 2½ inches, and deliver a total volume of 200,248 cubic feet per minute. When they are stopped, and the Sirocco fan is set to work at the speed named above, a periphery speed 100 feet per minute lower, a slightly higher water gauge is set up, fully 2½ inches, and the total volume of air delivered is over 226,000 cubic feet per minute, exceeding the duty of the two large Guibal fans, when working together, by nearly 26,000 cubic feet per minute. (*See fig.* 164.)

A comparison with the figures given in connection with other fans will show that the Sirocco fan, whilst not running at a higher periphery speed, is much smaller for the same duty, with a correspondingly smaller cost for the fan and engine, as well as for the engine house and foundations.

THE RATEAU VENTILATOR.

Although the names of Guibal—long associated with mechanical ventilators—and Schiele do not indicate British origin, the fans to which those names have been attached have perhaps been more largely made and more extensively applied in Britain than elsewhere. Modern continental practice in colliery ventilation does not appear to afford much information of a particularly striking character. The mechanical ventilator which one has perhaps heard most about in connection with continental practice is the Rateau; but although much has been written about this fan, so far we have failed to discover any specially important features, or that to any remarkable extent it exceeds the results achieved by the fans already described. Its construction would appear to be somewhat complicated, and from figures given it seems to excel in setting up excessive water gauges rather than moving large volumes of air. Nor is the useful effect any higher than can be shown by some of the fans previously dealt with.

There appear to be about thirty-two blades, of peculiar shape, curved forward in the direction of rotation. A volute or spiral-shaped passage surrounds the circumference of the

blades, and into this the air is discharged. This passage gradually increases in area, and finally emerges into the expanding chimney.

The general idea of the Rateau fan is illustrated in fig. 165.

From what has already been said, it will have been gathered that comparisons of fans working at different collieries, and the results obtained, are of little or no practical value. To be of any use the fans should be put to work under exactly similar conditions, and since the airways of the mine impose conditions for which the fan is in no way responsible—conditions which are rarely alike at two different mines—it follows that any comparison of the work done by one fan at one colliery with the work of another fan at another colliery cannot fail to be misleading.

One way of comparing fans, so far as what is called their "manometric efficiency" is concerned—that is, the water gauge they can set up at a given speed,—is by completely closing up the inlet and noting the depression, or water gauge, set up at various periphery speeds. The "equivalent orifice" may be applied to enable the useful effect of the fan to be determined.

Of course it will be understood that the volume of air a fan can deal with at any particular water gauge depends upon the capacity of the fan, or upon what has been called its "orifice of passage." This, it may be explained briefly, means that the total volume of air which a fan can pass at any given pressure depends upon its own internal resistance and capacity—upon its dimensions. For example, consider the case of two fans, both of the same type, both of the same diameter, both working under the same conditions and at the same speeds, but differing in width. It will be evident that whilst the water gauge set up will be the same in both cases, the volume of air passed through each fan will depend upon the width, and if one is twice as wide as the other, it follows that the larger fan will practically pass twice the volume of air.

It will thus be seen that whilst the circumferential velocity of a fan determines the water gauge set up, the dimensions of the fan determine its volumetric capacity. Generally, for a given volume, a fan of large diameter will be comparatively

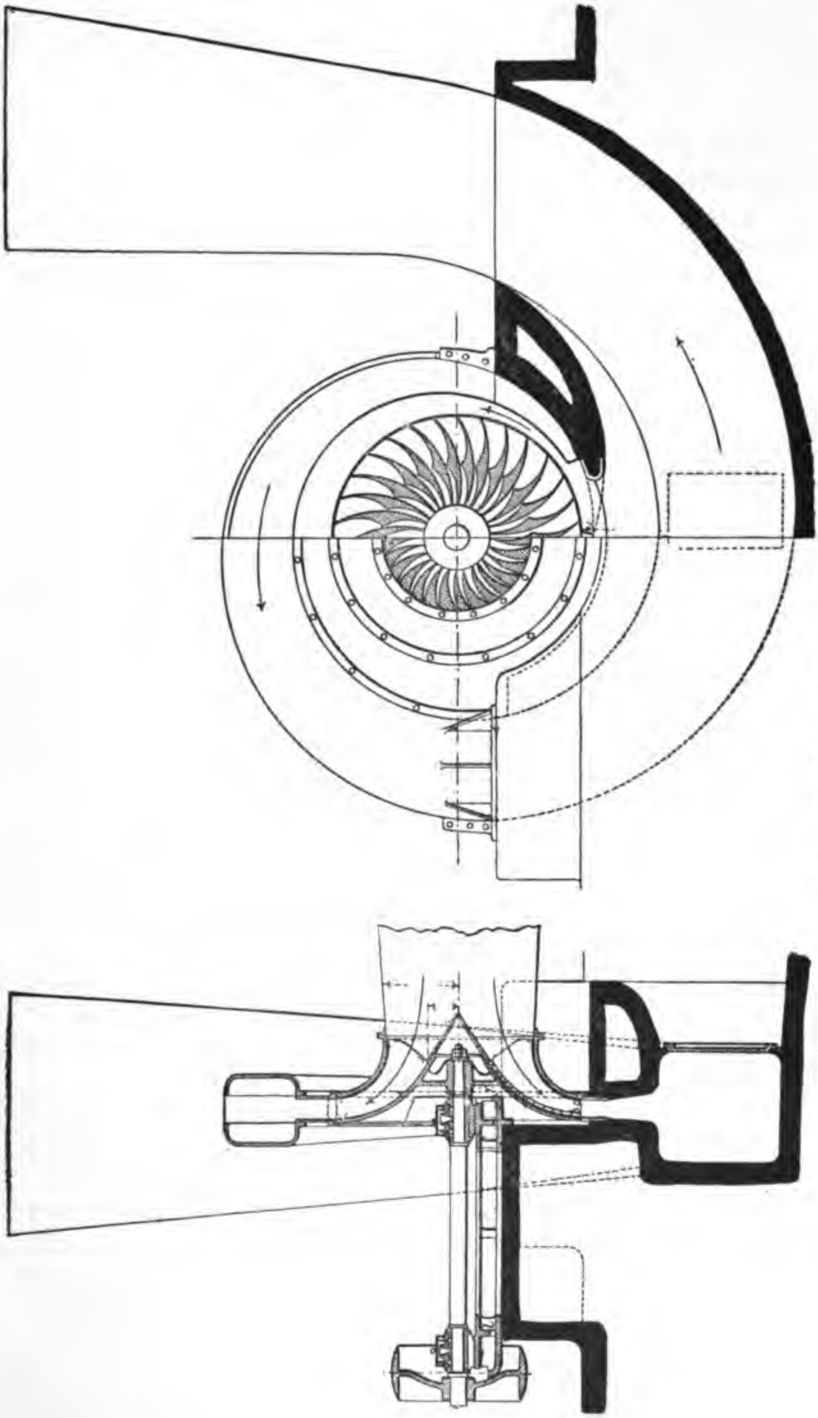


FIG. 165.—THE RATEAU VENTILATOR.

narrow in width, whilst for the same volume a small-diameter fan will be wider in proportion to its diameter.

THE EQUIVALENT ORIFICE.

For the purpose of comparing mine airways, and the resistance offered to the flow of air, the equivalent orifice has been introduced, which may be described as a standard to which the mine airway resistance may be reduced for purposes of ready comparison. Suppose we have a large compartment, or a large passage, in which a thin plate can be set up so as to enable a difference of atmospheric pressure to be maintained on the two opposite sides. Suppose, for the moment, that this thin plate forms an air-tight division, so that no flow of air from the one side to the other is possible. If, now, a small opening be made the air will flow through, and the volume passing will depend upon the difference of pressure and upon the size of the opening. If the pressure remains constant, and the opening is gradually enlarged, it will be evident that the volume passing will increase. Clearly, then, the opening in the plate constitutes a resistance, the amount of which decreases as the opening enlarges, and the resistance of the airways of any mine can be compared to the size of opening which, under the same pressure, will allow exactly the same volume to pass.

For example, suppose we have a mine through the airways of which a volume of air passes amounting to 200,000 cubic feet per minute, with a ventilating pressure of, say, 4-inch water gauge. We desire to know the size of the opening which, with a 4-inch water gauge, would allow 200,000 cubic feet per minute to pass.

The theoretical velocity with which the air would flow is the same as that which a falling body would acquire in falling through a vertical height equal to the column of air represented by a water column of 4 inches. Taking an inch of water column as being approximately equal to 70 feet of air column, this would give a theoretical velocity of 8032 feet per minute, and if the opening be exactly one square foot, the volume which would pass would, theoretically, be 8032 cubic feet per minute. As a matter of fact, however, it would not be so much, indeed only about two-thirds, on account of what is

called the *vena contracta* of the opening, which reduces the effective area to about two-thirds of a square foot, and the volume of air which actually would pass would only be about 5355 cubic feet per minute.

The following rule is usually given for calculating the area of the equivalent orifice: Multiply the quantity, expressed in thousands of cubic feet per minute, by ·37, and divide by the square root of the water gauge in inches; the result is the area of the opening in square feet. As the reader may possibly be confused in comparing different authorities on this subject by the figures variously given instead of ·37, it may be explained that the actual value of this constant depends upon the figure taken as the density of a cubic foot of air, which forms the basis of the calculation. The difference is not serious, and as the practical result is the same, we shall not go far wrong in accepting ·37.

Working back, for example, in the case given, and taking two-thirds of the theoretical volume as the volume actually passing, we get 5355 cubic feet per minute, or, expressed in thousands, 5·355; multiply by ·37, equals 1·98135, and divide by the square root of 4, equals ·99067, or, practically, 1 square foot. The slight error is due to not having worked out the results to a sufficiently large number of places of decimals.

Applying this rule now to the conditions first proposed—that is, 200,000 cubic feet per minute, with a 4-inch water gauge—the quantity expressed in thousands equals 200:—

$$\frac{200 \times \cdot 37}{\sqrt{4}} = \frac{200 \times \cdot 37}{2} = 37 \text{ square feet.}$$

In other words, 37 square feet is the equivalent orifice of a mine which, with a ventilating pressure of 4-inch water gauge, will pass 200,000 cubic feet per minute.

As a further example, take a mine passing 173,000 cubic feet per minute, with 3-inch water gauge: Proceeding as before—

$$\frac{173 \times \cdot 37}{\sqrt{3}} = \frac{173 \times \cdot 37}{1 \cdot 73} = 37 \text{ square feet,}$$

showing that the equivalent orifice of these two mines is the same; that is to say, they both offer the same resistance to the flow of air, and the same ventilating pressure would cause the same volume to flow in each case.

Now take the example of a mine passing 300,000 cubic

feet per minute, with a ventilating pressure of 4-inch water gauge: $\frac{300 \times \cdot 37,}{\sqrt{4}}$ giving an equivalent orifice of 55·5 square feet, indicating a very much better state of affairs than represented in the other two cases.

If the reader will work out the equivalent orifice from the figures given on page 263, showing the relative proportions of quantity and pressure, he will find that a fair average equivalent orifice of British mines is from 35 to 50 square feet. If the orifice works out to anything much less than this, either the airways are in an indifferent condition, or there are exceptional circumstances prevailing, which impose excessive resistance to the flow of the ventilating volume.

It is good practice, in mine ventilation, to have a large equivalent orifice. Perhaps this point may be made more impressive by reducing it to hard cash. Suppose we have a mine for which the equivalent orifice is small, and the volume passing is 200,000 cubic feet per minute, with a 5-inch water gauge: $\frac{200{,}000 \times 5 \times 5 \cdot 2}{33{,}000}$ = say, 157 horse power in the air.

Assume a combined efficiency of 66 per cent for the fan and engine, or, say, 235 indicated horse power of the fan engine.

We will assume that a high-class compound condensing engine is employed to drive the fan, in which the coal consumption amounts to two pounds per indicated horse power hour, and say the fan runs for 8600 hours during the year (it will most probably do more): $235 \times 2 \times 8600 \div 2240$ gives, say, 1800 tons per year, and for the purposes of this example we may put down the value of the fuel at *5s.* per ton, giving an annual expenditure of £450, or, with a good simple engine (non-compound), £900.

Now, suppose that the conditions in this mine can be so far improved that the same volume can be sent through the workings with a pressure of 2-inch water gauge, which represents a fair pressure for the volume named: $200{,}000 \times 2 \times 5 \cdot 2 \div 33{,}000$ gives, say, 63 horse power, and taking the same efficiency as before, say, 95 indicated horse power of the fan engine, with the same fuel consumption (two pounds coal per indicated horse power hour) for a compound condensing engine, we get

$95 \times 2 \times 8600 \div 2240$ equals, say, 730 tons per annum, or £183 as against £450 in the one case, or £366 as against £900, assuming a non-compound engine—a saving of £267 and £534 respectively.

In the first example the equivalent orifice works out to 33 square feet, in the second 52. The lesson is obvious: a large equivalent orifice spells economy.

To judge from the figures we get from continental collieries relating to the ventilating volume and the ventilating pressures commonly prevailing—the former not very large, the latter excessively so,—it would appear that a very much inferior condition of things obtains in foreign collieries as regards the airways and ventilating arrangements underground.

We are, from time to time, urged by those of our friends who always see good features in every country but their own, to copy continental mining practice, and to model our educational methods in mining on continental lines. Of course, we, as a nation, are by no means perfect in all our methods, and no doubt there is room for improvement in many of our mining practices; but so far we have failed to discover that we are going to benefit to any extent by copying continental mining methods, or by modelling our educational institutions after theirs. Hemp ropes for winding, and 8 and 10-inch water gauges in ventilation, do not commend themselves as very admirable features. Continental methods certainly excel in one direction—in the large proportion of serious and fatal accidents, a record we have no ambition to attain, an example we are not eager to emulate.

SELF-RECORDING INSTRUMENTS.

In connection with the ventilation arrangements, a practice adopted at some collieries, and one to be strongly recommended, is that of employing self-recording instruments to show continuously the speed of the fan, the ventilating pressure, and, in some cases, the quantity of air passing through the mine. Records are traced out upon a chart, which can be filed for future reference.

Figs. 166 and 167 (*see pages* 310 *and* 311) will serve to explain the principle of a self-recording water gauge. An eight-day clock actuates the cylindrical drum at such a speed that it makes one complete revolution per week. Of course, if

preferred, the drum can be arranged to revolve once per day, but this necessitates changing the chart every day, and the number

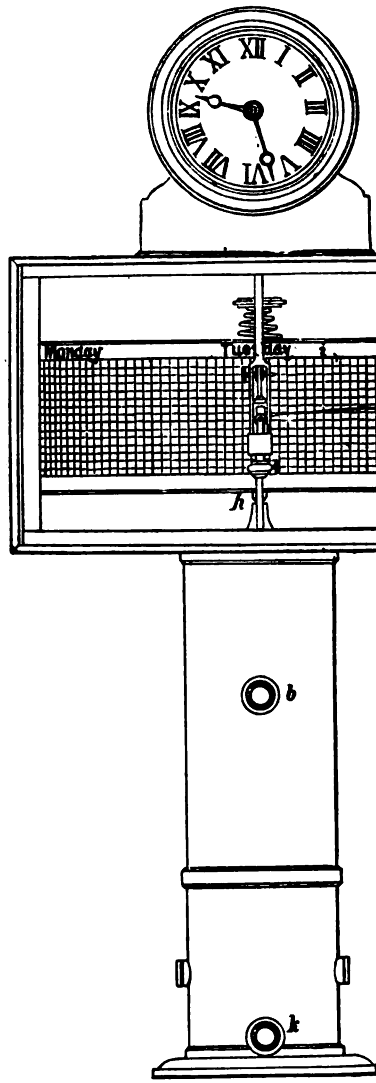


FIG. 166.
A RECORDING WATER GAUGE.

of charts accumulate rapidly, there being three hundred and sixty-five to file per year as against fifty-two. The paper

chart is divided by vertical lines into days and hours, and by horizontal lines into inches and tenths.

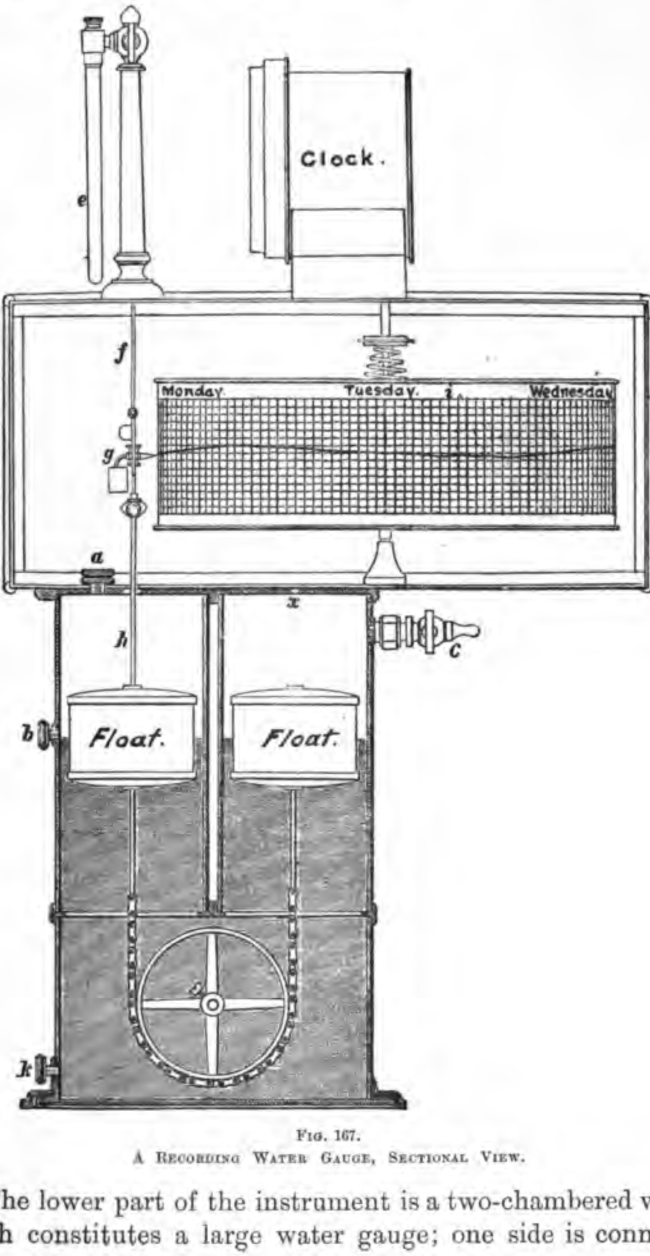


FIG. 167.
A RECORDING WATER GAUGE, SECTIONAL VIEW.

The lower part of the instrument is a two-chambered vessel, which constitutes a large water gauge; one side is connected

with the fan drift in the usual way, the other is open to the direct pressure of the atmosphere. In these two chambers are two floats, which, of course, rise and fall with the water level. To one of the floats a vertical rod is attached which carries a marking instrument, the point of which presses against the surface of the revolving drum, and traces out on the paper chart the variations of ventilating pressure.

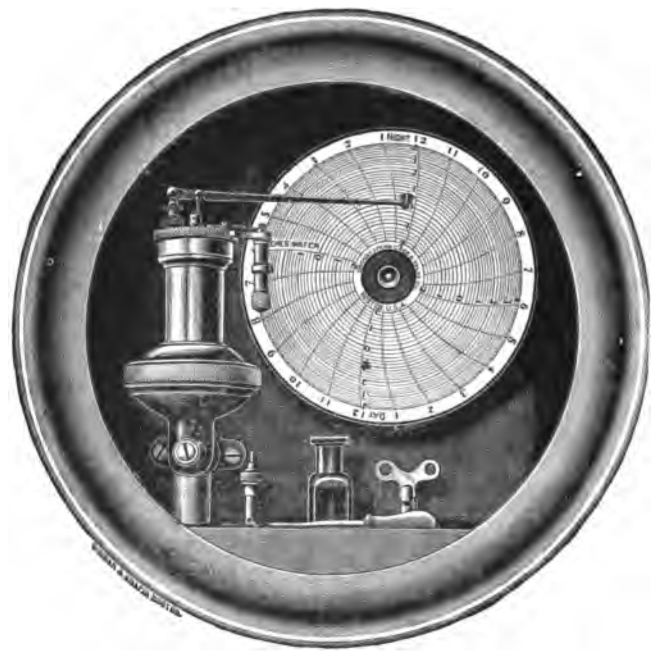


FIG. 168.
THE CROSBY RECORDING WATER GAUGE.

Fig. 168 shows another type of water-gauge recorder, made by the Crosby Steam Gauge and Valve Company, of 147, Queen Victoria Street, London. This instrument gives daily charts which are circular. The disc is revolved by a clock, as before, and the marking instrument is actuated by the direct pressure of the air upon the mechanism contained in the small cylinder seen on the left side of the disc.

The same firm makes a somewhat similar instrument for recording on a circular disc chart (fig. 169) the variations of steam pressure, either at the boilers or at the fan engine, or, for the matter of that, any other engines to which it may be desired

to apply such an instrument. It will also serve as a means of securing continuous records of the pressure variations in the receiver of the air compressor.

Whilst speaking of instruments of this character, it may not be out of place to introduce the steam-engine indicator.

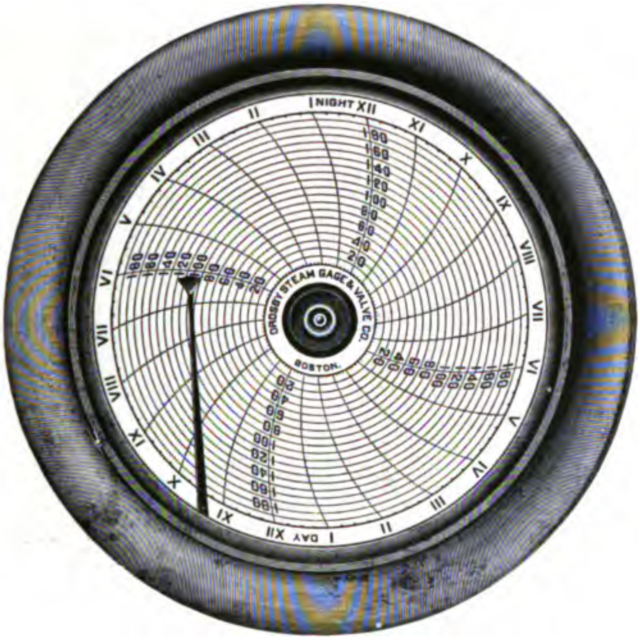


Fig. 169.
Crosby's Recording Steam-Pressure Gauge.

It is often desirable to know exactly what is going on in the cylinders of the fan engine, or any other engine, for which purpose we require an indicator diagram. Such a diagram will indicate clearly the defects or otherwise of the engine; it will show the prompt admission of steam at the commencement of the stroke; or will, on the other hand, show that steam is admitted late; it will show the point at which steam is cut off and the expansive working commences; it indicates the opening of the exhaust valve, and the back pressure during the return stroke. From an inspection of the indicator diagram we can ascertain the pressure operating in the cylinder at any point during the stroke; we can calculate the indicated horse power. In a word, we can see if the engine is working under

the best conditions possible, or if defects exist which may be remedied so as to increase the efficiency of the engine. Of course, the instrument, which in this way feels the pulse of the engine, must itself be perfect, and we are enabled, through the courtesy of the firm already named, the Crosby Steam Gauge and Valve Company, to reproduce illustrations of their steam engine indicator. (*See fig.* 170.) This instrument may be

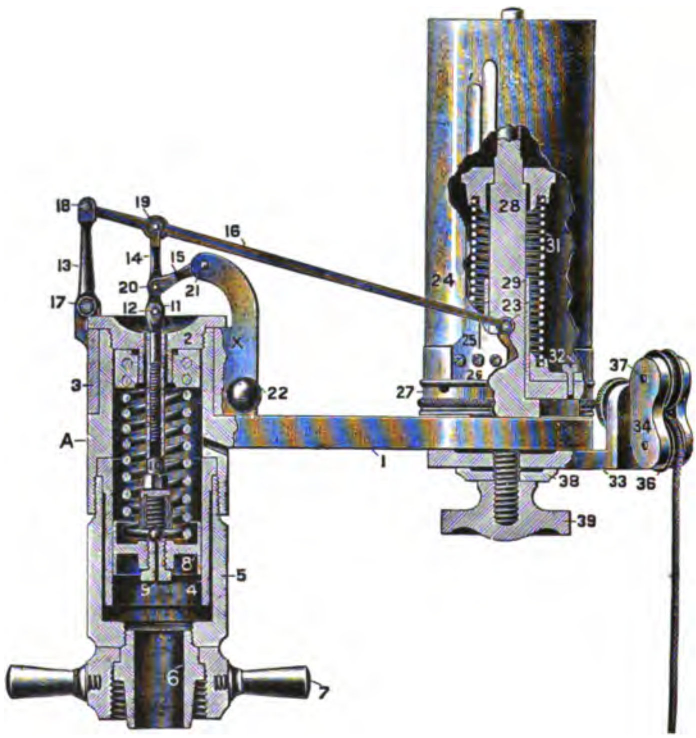


FIG. 170.
THE CROSBY INDICATOR.

regarded as representing one of the highest possible standard of excellence. It is light in all its moving parts, reducing the effect of inertia and momentum, a matter of importance in indicating engines running at a high speed. The spring which the steam compresses when operating in the indicator cylinder is exceedingly ingenious; it consists of a double coil, wound from the middle of a single piece of steel wire. (*See fig.* 171.) This spring has a small steel bead attached to the wire at the

bottom, in place of the usual brass foot attached to indicator springs, thus reducing the weight to a minimum.

FIG. 171.
THE SPRING USED IN THE CROSBY INDICATOR.

The pencil mechanism has been carefully designed, in order that it may have sufficient strength and steadiness combined with the utmost lightness. The movement of the pencil is six times that of the piston.

This Crosby indicator can be fitted with a drum, on which continuous diagrams may be taken, if desired.

These instruments are simply constructed, and may be easily operated by any engineer of ordinary ability.

We also illustrate the Crosby reducing wheel (*see fig.* 172), which has been designed for use in conjunction with the Crosby indicator, to reduce the stroke of an engine, easily and correctly, to the length of the diagram to be taken on the indicator drum.

This reducing wheel is compact and simple, being attached directly to the cylinder cock and to the indicator. It is provided with a series of speed pulleys, which make the reducing wheel available for use on any engines having strokes between 14 inches and 72 inches; it is thus a particularly useful instrument, as it can be taken about from one engine to another.

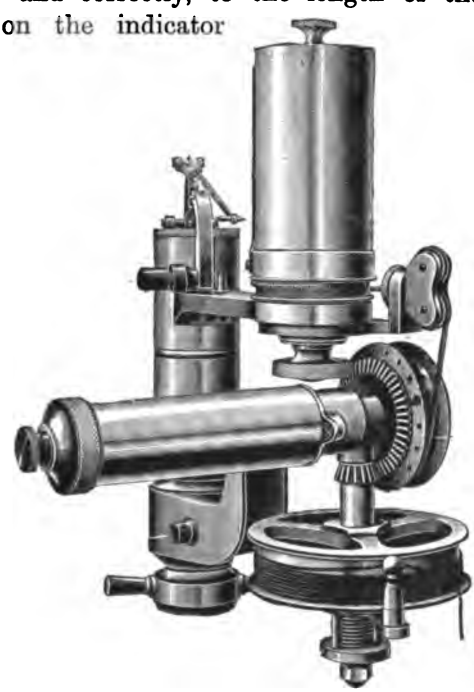


FIG. 172.
THE CROSBY INDICATOR FITTED WITH THE REDUCING WHEEL.

By the aid of this

instrument an engine can be indicated in a few minutes, whereas formerly it would take some hours to rig up reducing gear.

The bearings are nicely adjusted, and made practically frictionless by the use of ball bearings.

CHAPTER VII.

HAULAGE.

IN dealing with this section of the subject, the writer derives considerable satisfaction from the fact that the title, "Mechanical Equipment of Collieries," absolves him from any necessity to introduce a system which has little to commend it from any point of view, and one of which he has never been enamoured—haulage by animal power underground. Next to haulage by manual labour it is the most costly system, and as a matter of sentiment—if sentiment may find a place in a work of this character—there is much to be said against the system.

No doubt pit ponies are, in many cases, well treated and well cared for; on the other hand, the writer has known instances where they were *not*. Perhaps he is unusually susceptible where dumb animals are concerned, but he cannot refrain from using his pen in strong protest against those barbarous appliances for utilising animal power, especially in a mine, consisting of a radial beam attached to a vertically revolving shaft, to which some wretched animal is yoked, to pace round and round a narrow circle for hours at a time.

Turning at once, then, to those systems of haulage which properly come within the scope of this book, we may at the outset refer generally to those appliances which are common to all colliery hauling systems—the wagons, boxes or tubs, the rails, and the sleepers.

PIT TUBS OR BOXES.

(WAGONS, CORVES, ETC.)

In construction and capacity there is considerable variation in different districts. Wooden-bodied tubs are still very largely

used; steel-bodied tubs are gradually gaining in favour. No doubt there is much to be said in favour of retaining the one, whilst the other offers undoubted advantages.

A very popular type of tub is a sort of compromise between the two—namely, wooden sides and ends, with a steel bottom.

It is found in some cases that a tub of this description proves to be less costly in upkeep—repairs—than the all-steel type. Much would appear to depend upon the character of the mine, however. In very steep seams the breaking away of a gang—an accident which may happen in the best-regulated colliery—the destruction of the tub, wooden or steel, is complete, and the cost incurred with all-steel tubs would be greater than with the type above described. On the other hand, where the tubs are not liable to such violent treatment, the steel-bodied tub possesses all the advantages claimed for it, together with reduced cost for maintenance and repairs.

The capacity of pit tubs is governed very largely by the thickness of the mines in which they are used, and they range from about 1½ to 2 cwts. in thin mines, to the large wagons employed in some of the South Wales collieries, holding from 20 cwts. to 2 tons.

Excluding these extremes, the average size in Lancashire collieries is from 6 to 8 cwts. capacity, the tendency being to adopt the rather larger sizes, of 10 to 12 cwts. capacity, met with in the Midlands.

The wooden-bodied tub is usually of rectangular pattern, as represented in fig. 173. Steel-bodied tubs are constructed either with wooden underframes, or are entirely built of steel. The advantages claimed for steel-bodied tubs are increased capacity for the same external dimensions, and decreased cost, due to a longer life. An important advantage which has often suggested itself to the writer is this, the steel-bodied tubs, having no narrow slits in the sides and bottoms, as is the case between the edges of the boards used in the construction of wooden-bodied tubs, do not scatter and deposit small coal all along the haulage planes. The jolting and shaking of the coal in the tubs produces a considerable amount of small coal, which ordinarily finds its way through the joints, to be deposited all along the haulage planes, and this small coal, in dry and dusty

mines, contributes largely to the coal dust, which, as we know, may constitute a serious element of danger.

Messrs. Graham, Morton & Company make a steel tub, of which the box is stamped out of one piece of steel. Usually they are constructed of three plates, one forming the bottom, the other two forming the ends and sides.

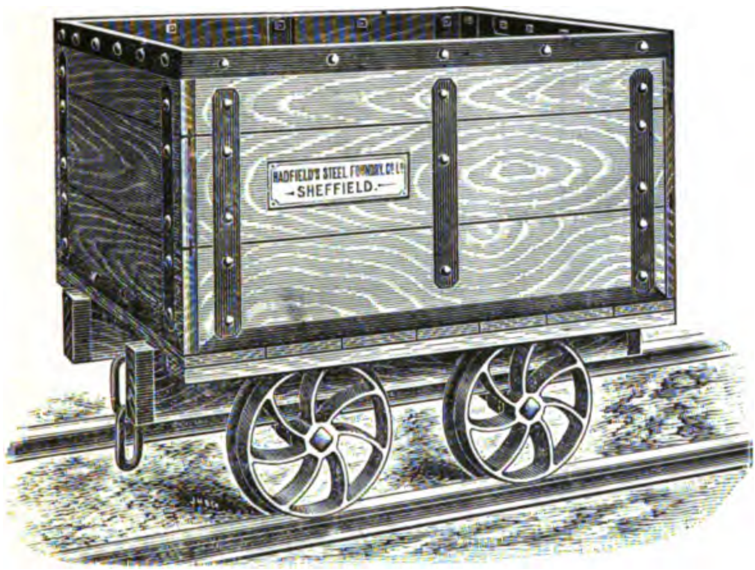


FIG. 173.

As showing the relative capacities of a steel-bodied and a wooden-bodied tub, the following particulars may be interesting:—

The external dimensions are the same in each case—namely, 4 feet by 3 feet by 2 feet 6 inches deep; the wooden body is built of larch boards, the bottom $1\frac{1}{2}$ inches thick and the ends and sides $1\frac{1}{4}$ inches.

The external cubical measurement is 30 cubic feet, the internal capacity practically 25 cubic feet, which will accommodate 10 cwts. of coal in the broken state; the weight of such a tub is about 5 cwts.

The steel box has the same external dimensions, but the bottom plate is $\frac{3}{16}$ of an inch thick, and the sides and ends $\frac{1}{8}$th; the internal capacity works out to nearly $29\frac{1}{2}$ cubic feet, a gain

of more than 4 cubic feet, bringing the accommodation for coal up to 12 cwts.; the tub itself weighs 6 cwts.

At a colliery where 2000 tubs are wound per day, this means an increased output of 200 tons, with the same number of windings and the same number of tubs to handle, a decidedly important advantage in favour of the steel tub.

The type of tub adopted largely on the Continent presents certain striking points which should engage the attention of British colliery engineers. The shape of the body, as seen in the end view, is as shown in fig. 174.

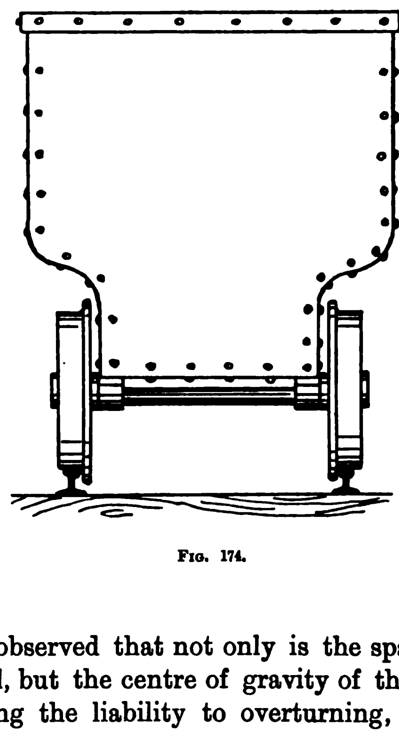


FIG. 174.

It will be observed that not only is the space between the wheels utilised, but the centre of gravity of the tub is brought lower, lessening the liability to overturning, and it becomes possible to employ larger wheels, thus reducing the rolling friction. As these tubs are made of iron or steel, they are almost as easy to build as the rectangular shape.

WHEELS AND AXLES.

Formerly the wheels were made loose on the axles and the

axles loose in the pedestals. There was, indeed, too much looseness about the arrangement altogether; it was impossible to maintain a uniform gauge, frequent derailment was the result,

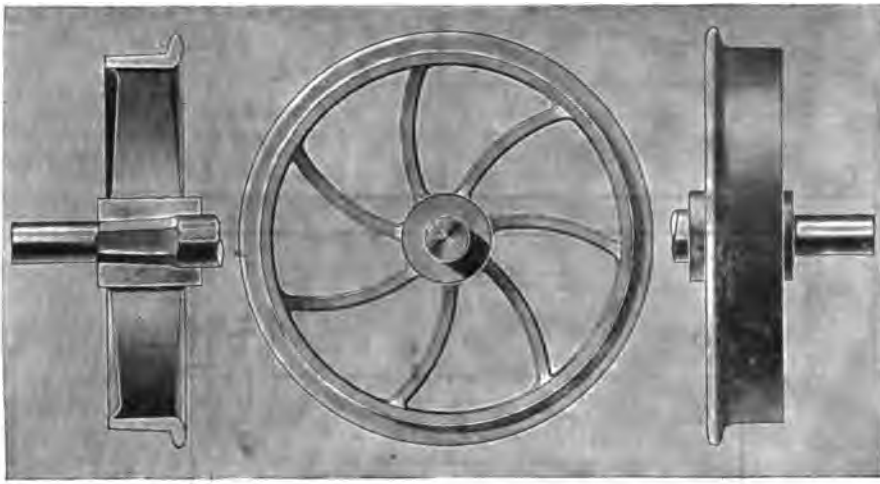


Fig. 175.
Hadfield's Steel Wheels and Axles for Colliery Tubs, Outside Bearings.

and the wear was excessive. Our opinion is that, so far as reasonably practicable, the haulage arrangements underground should copy as closely as possible the features in surface railways, and as regards the wheels these should be fast on the axles.

Fig. 176.
Hadfield's Tub Pedestal for Inside Bearings, intended to facilitate the use of Automatic Greasers.

The illustrations (figs. 175 and 176) furnished by the well-known makers, Hadfield's Steel Foundry Company Limited,

represent wheels, axles, and pedestals made entirely of steel. The pedestals, it will be observed, leave the lower half of the axle exposed, so as to admit of the employment of automatic tub greasers, most valuable adjuncts to an underground haulage system. (*See figs.* 177, 178, 179 *page* 324, 180 *page* 325, 181 *page* 326, *and* 182 *page* 327.)

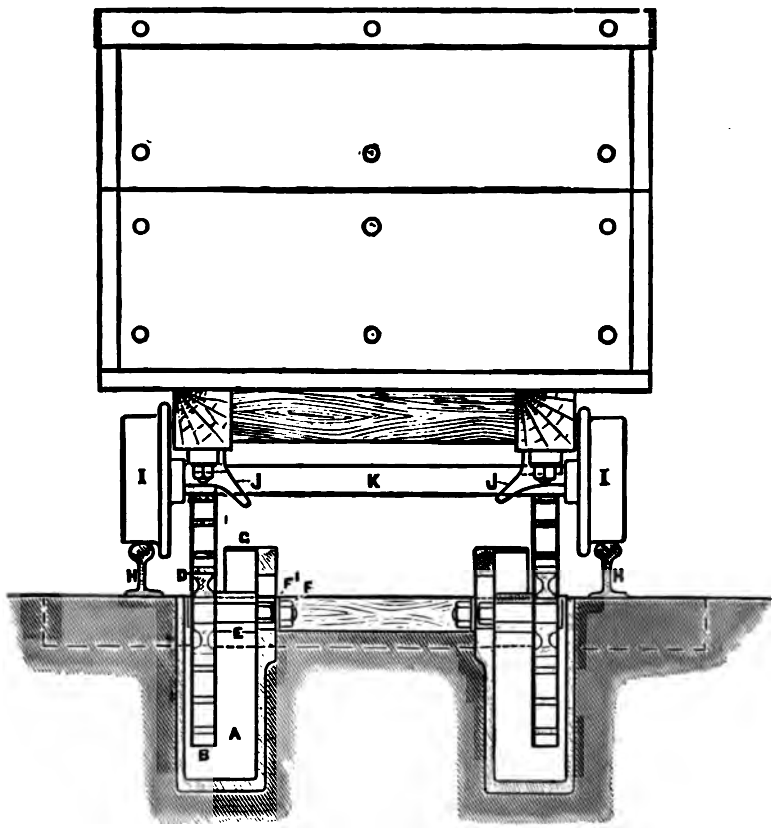


FIG. 177.

HADFIELD'S AUTOMATIC TUB GREASER, END VIEW.

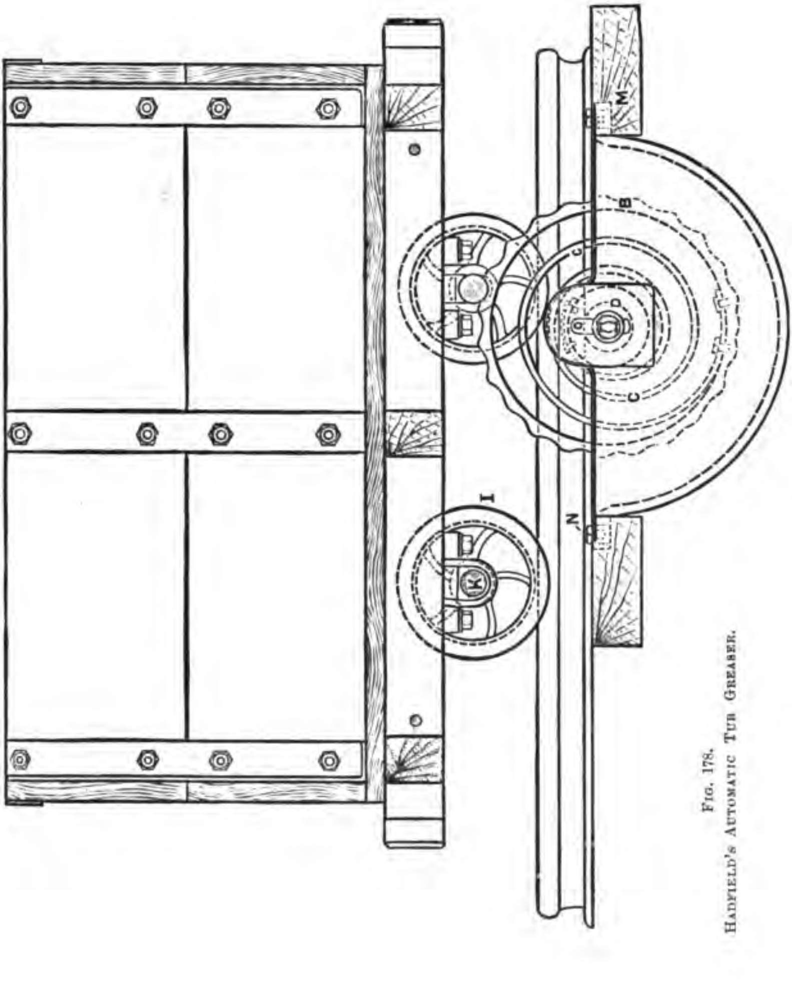


FIG. 178.
HADFIELD'S AUTOMATIC TUB GREASER.

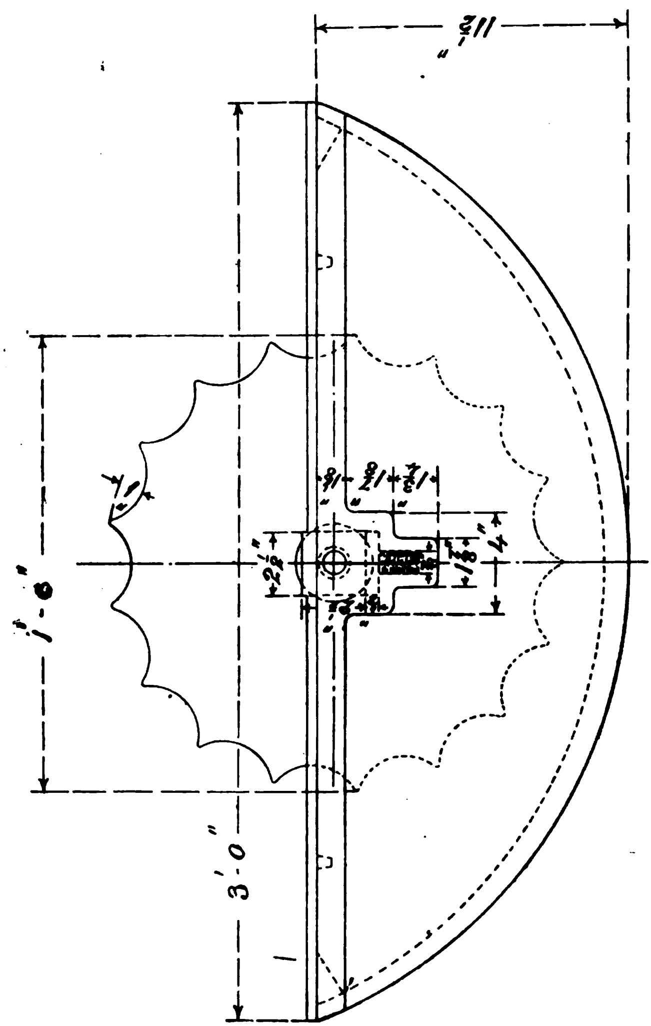


FIG. 179. ELEVATION OF AN AUTOMATIC TUB GREASER. MESSRS. JOHN WOOD & SONS LIMITED, WIGAN.

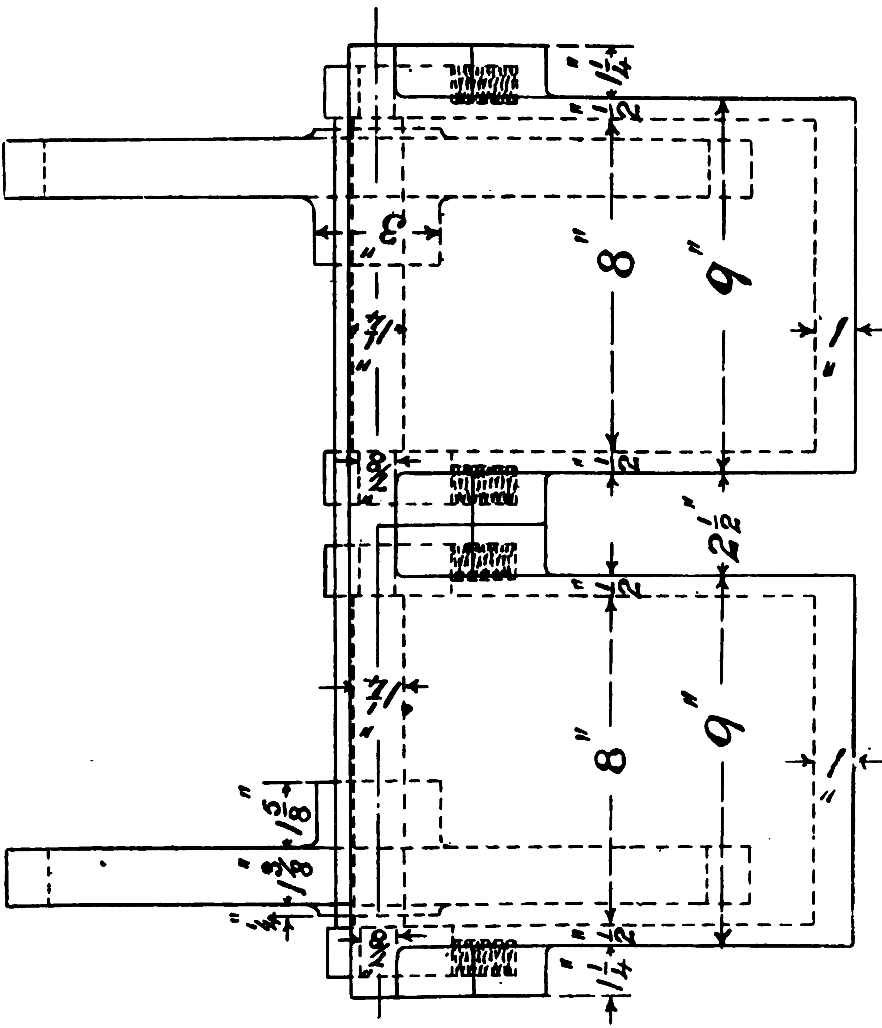


Fig. 180.

End Elevation of Tub Greaser. Messrs. John Wood & Sons Limited, Wigan.

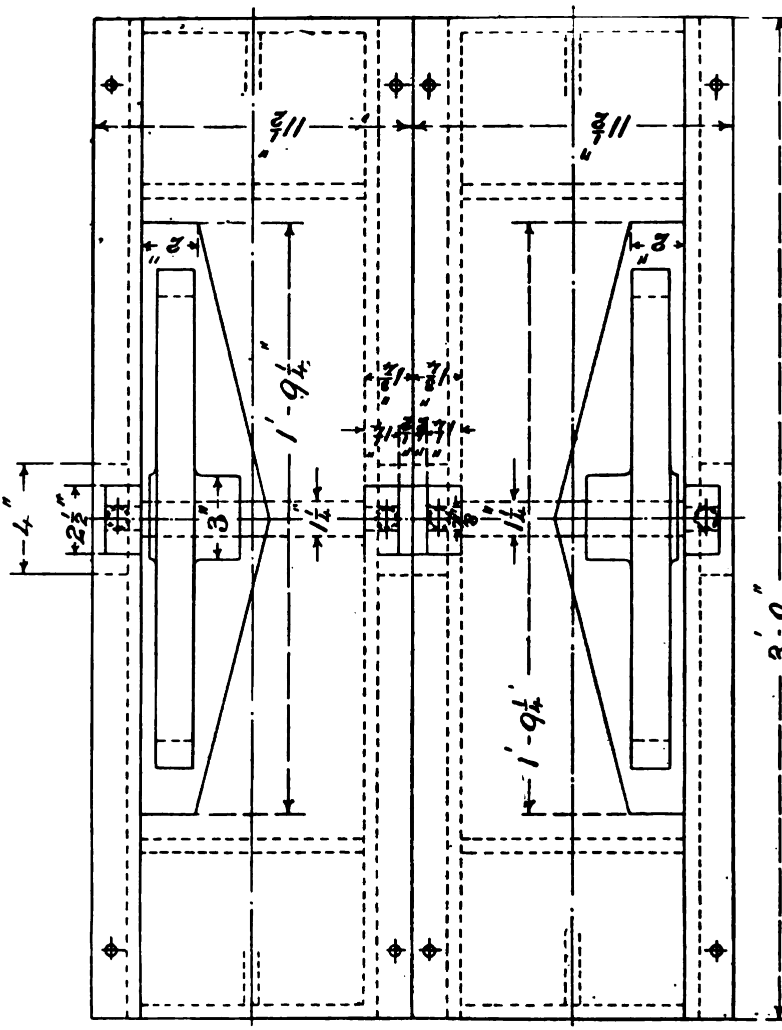


Fig. 181.

Plan of Tub Greaser shown in Figs. 179 and 180. (*See pages* 324 *and* 325.) Messrs. John Wood & Sons Limited, Wigan.

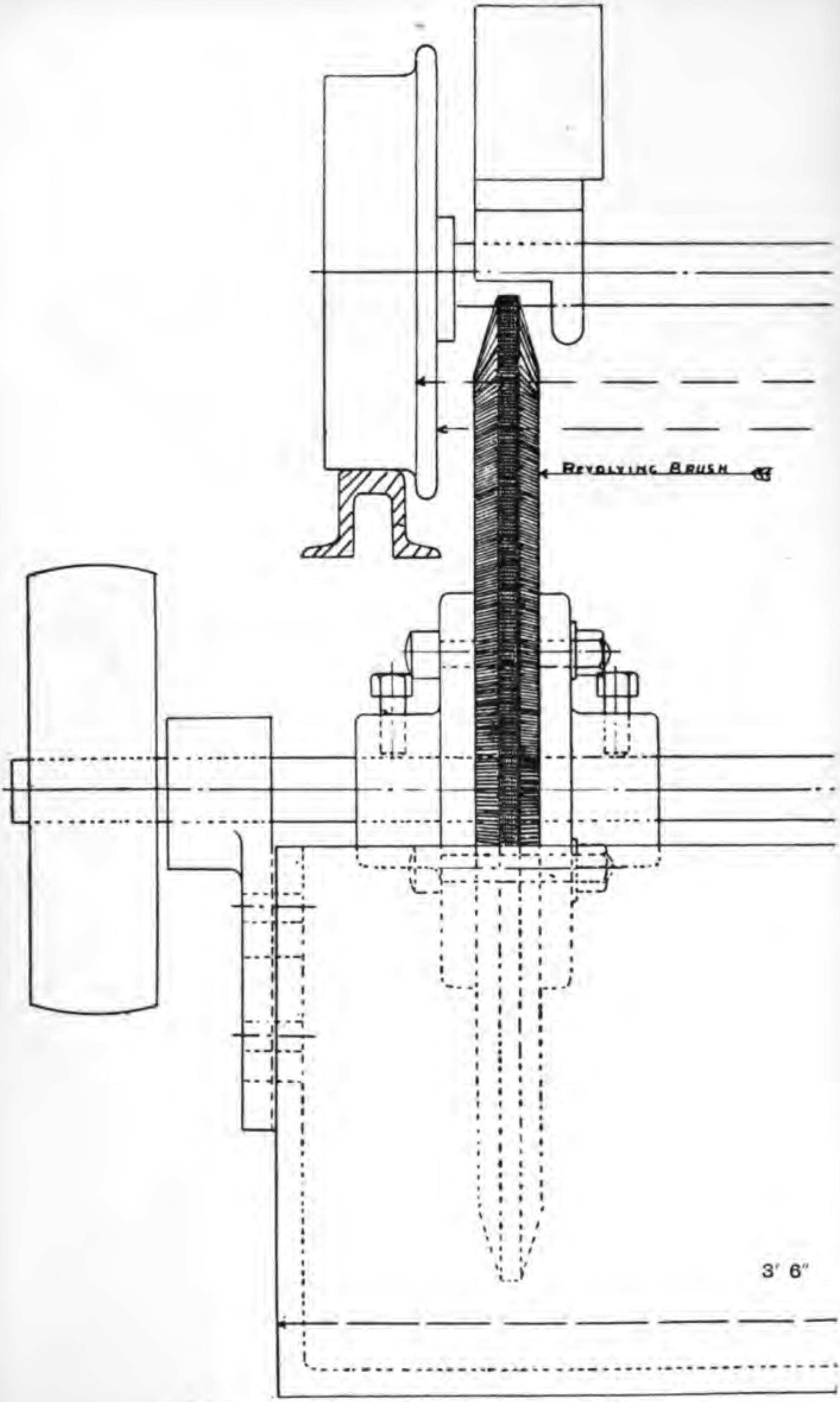


FIG. 182.—HALF ELEVATION OF DRIVEN TUB GREASER FOR PIT BANK.
MESSRS. JOHN WOOD & SONS LIMITED, WIGAN.

The bearings and pedestals are usually inside the wheels; recently several makers have introduced the outside bearings, not unlike those used on railway wagons. These journals work in self-lubricating pedestals, of which the Hardy Patent Pick Company make a well-known type. (*See fig.* 183.)

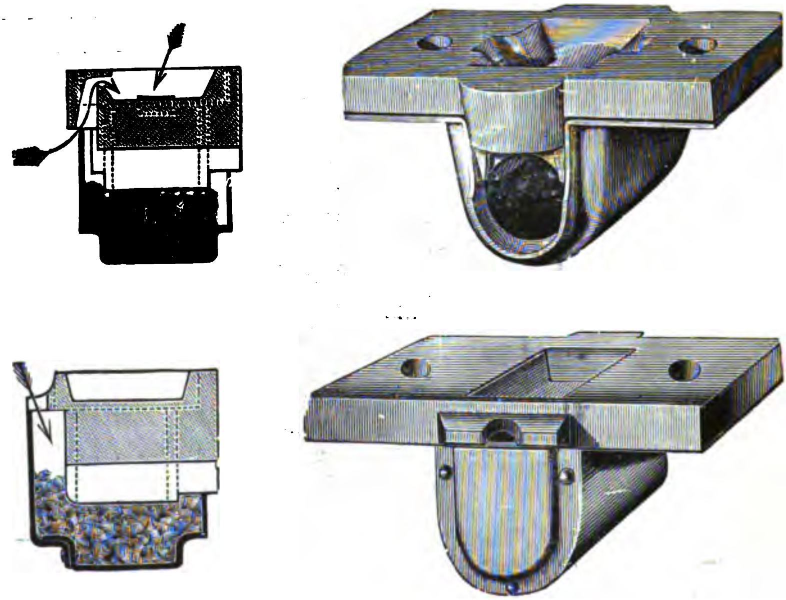


FIG. 183.

THE HARDY PATENT PICK COMPANY'S SELF-LUBRICATING PEDESTALS FOR PIT TUBS.

RAILS AND SLEEPERS.

The writer has long sought, and in vain, for some explanation of the popularity of the bridge section rail. Without a single redeeming feature it still finds a place at many collieries, and seems to possess a fascination for some people which is quite inexplicable. It is wrong in design; it is heavy in proportion to its strength, and therefore unnecessarily costly; it offers two thicknesses of metal where there should be none; it presents an open space where there should be solid metal; it lacks stiffness and offers no means of effecting a good permanent joint with its fellows.

The best section of rail is undoubtedly the flat-bottomed

girder section, which is lighter, stronger, cheaper, lasts longer, and is more convenient in use. It lends itself readily for "fish-plating" at the joints, and on main haulage roads the joints should always be fish-plated.

The usual sections for colliery haulage weigh from 10 to 26 pounds per yard. The light sections are used in the gate roads or wagon roads communicating with the working places; the heavier sections are used in the main haulage roads. The weight of the tubs and the haulage speed is also taken into account in selecting a suitable weight of rail.

The width between the rails or gauge varies from 18 to 30 inches, 24 inches being the average.

In main haulage roads it is important to lay the rails with care, following as far as possible the same rules as are adopted on a surface railway. The extra trouble is more than repaid by the smooth working of the haulage system. Not only should they be laid carefully at the outset, but afterwards properly maintained. No doubt with lifting floors and crushing sides the difficulties are greater than on the surface, but it is better to effect repairs as occasions arise than to wait until the haulage system is disorganised and possibly considerable damage done.

The gauge should be strictly maintained. One commonly used when laying rails is the length of the man's arm plus the width of his hand—a sorry substitute for the proper rail gauge. Is it to be marvelled at that difficulty is experienced in keeping the tubs on the rails?

Gradients should be uniform, and where changes necessarily occur they should be tailed out or graduated as far as practicable.

Curves should *be* curves, and not a succession of short, straight rails. They should be carefully and accurately bent to the proper radius, and the gauge in rounding corners should be slightly increased.

The best system of securing the rails to wooden sleepers is by means of dog spikes. The sleepers should be placed at equal distances, and should be properly bedded, so as to ensure equal and uniform support to the rails and avoid bending.

Steel sleepers appear to be coming into use. There are

several types, some of which are illustrated in figs. 184, 185, and 186; these sufficiently explain themselves.

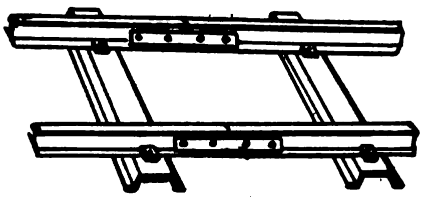


FIG. 184.

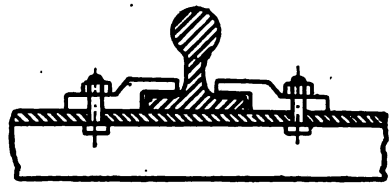


FIG. 185.

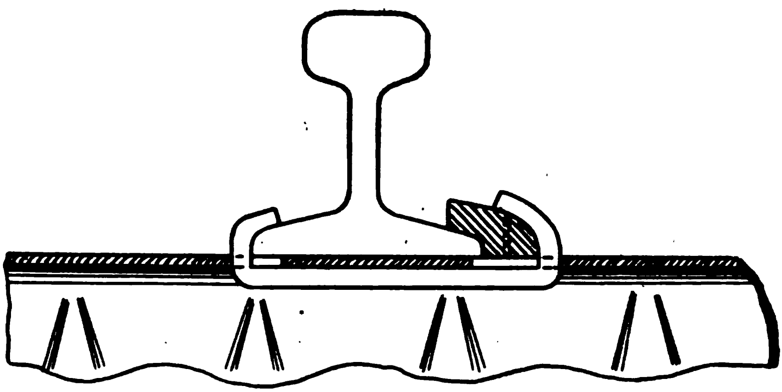


FIG. 186.
SHOWING METHOD OF SECURING RAIL TO STEEL SLEEPER.

SYSTEMS OF HAULAGE.

The varied conditions under which coal seams occur in the earth's crust render several systems of haulage necessary, suited to the particular requirements of each case, and it would not be possible to speak of any one system as being universally applicable, although the writer is familiar with endless-rope haulage in successful operations in mines with varying inclinations from nearly horizontal to 45 degrees dip.

Haulage by locomotives, whether steam, compressed air, or electrical, presents difficulties in connection with British mines which have almost entirely precluded their application underground, although they are used to a considerable extent in the coalfields of America.

Practically all haulage—mechanical haulage, that is—in British collieries is effected either by rope or chain, three systems, with modifications, being possible—namely, direct rope haulage, main-and-tail rope haulage, and endless-rope haulage. In the latter system the substitution of a chain for the rope gives the endless-chain system.

POWER FOR HAULAGE.

Excluding animal power and manual labour, the power applicable for colliery haulage may be steam, compressed air, or electricity. Under favourable circumstances gravitation furnishes all the power requisite, such being the case where the inclination of the mines is suitable, and where all the workings lie on the higher side of the shaft level. It will, perhaps, be convenient at this point to give some information with reference to self-acting inclines.

SELF-ACTING HAULAGE.

Self-acting inclines are extensively used in secondary haulage, where the mines are sufficiently inclined, for lowering

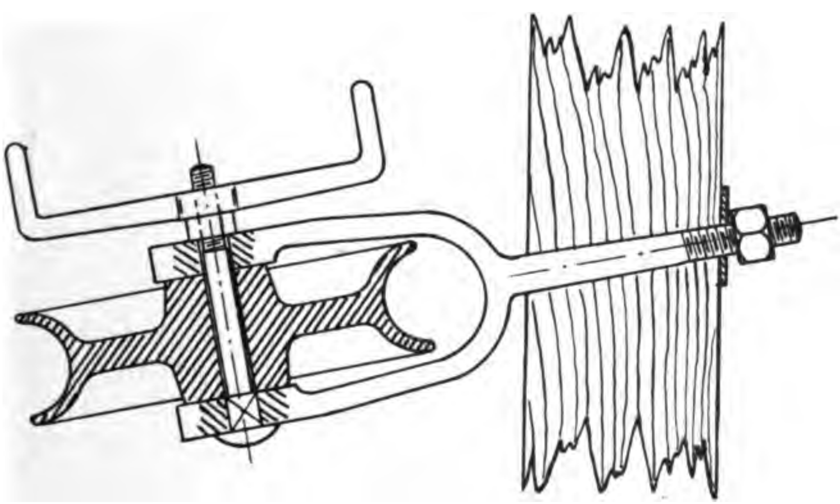


Fig. 187.

the tubs from the working faces, singly or in couples, to the main levels or cross roads, which, in turn, communicate with the main haulage planes. For this purpose the appliances are

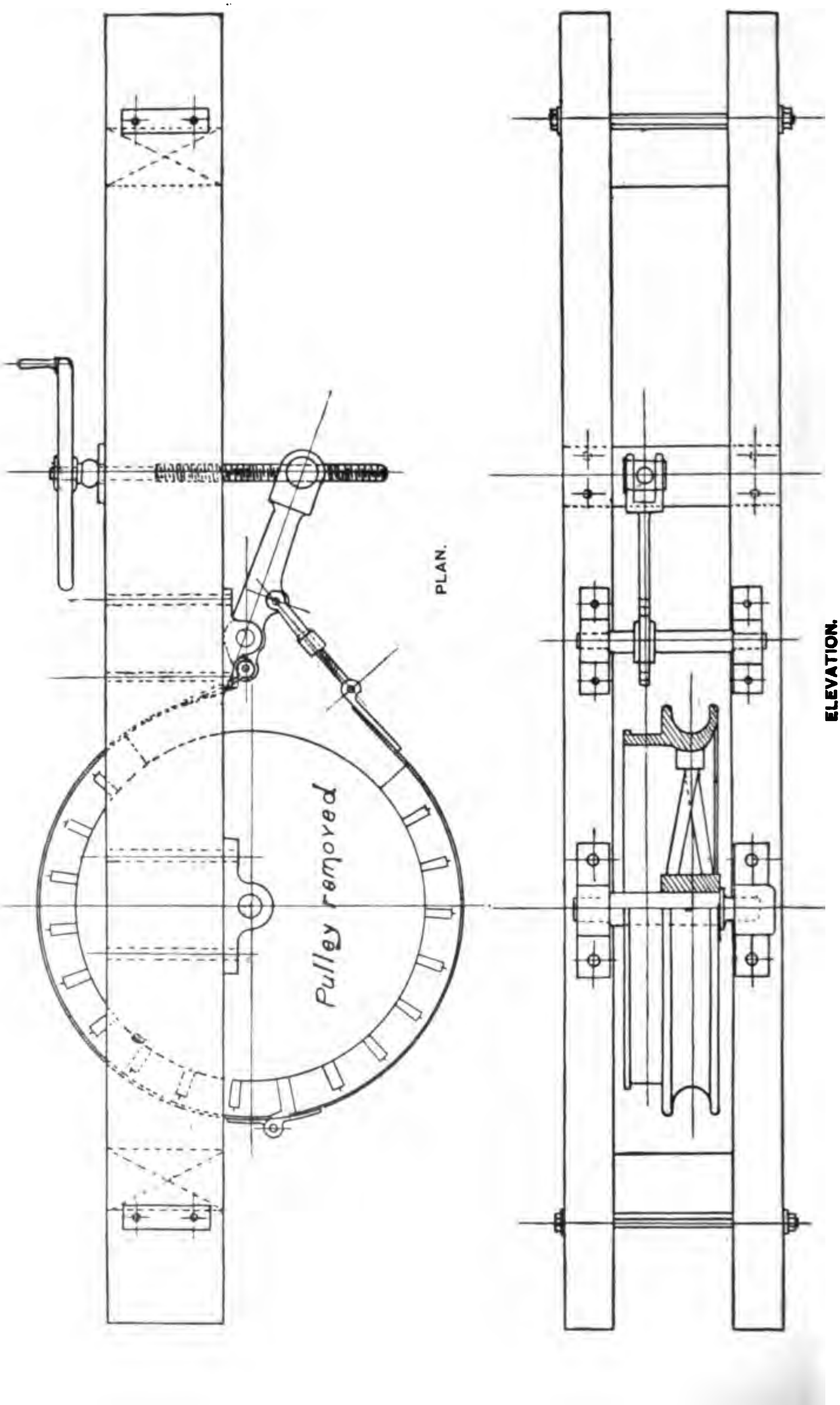


Fig. 188.—Plan and Elevation of Jig Wheel and Frame. Messrs. John Wood & Sons Limited, Wigan.

usually of a very simple character. The arrangements shown in fig. 187 (*see page* 331), figs. 188 and 189 are typical of these jigging appliances. In some cases the screw-brake arrangement is dispensed with, and a prop is used as a braking appliance, the end of the prop being inserted between the fork and the jig wheel, and used as a lever.

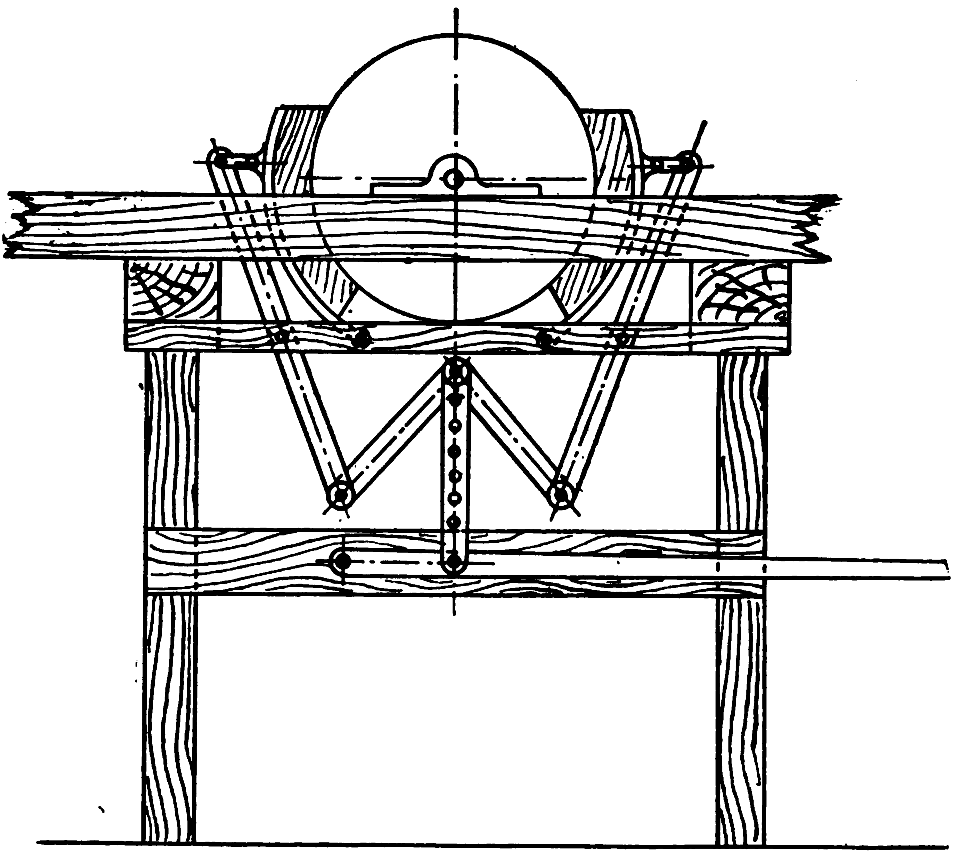


FIG. 189.

In steep mines, and on main jig brows or self-acting planes, the appliances are necessarily of a more elaborate character. The wheels or pulleys are larger, and mounted in strong frames, and equipped with powerful brakes. (*See figs*. 188, 189, *and fig*. 190, *page* 334.) The rope will make two or three turns round the wheel to afford the necessary grip; this, of course,

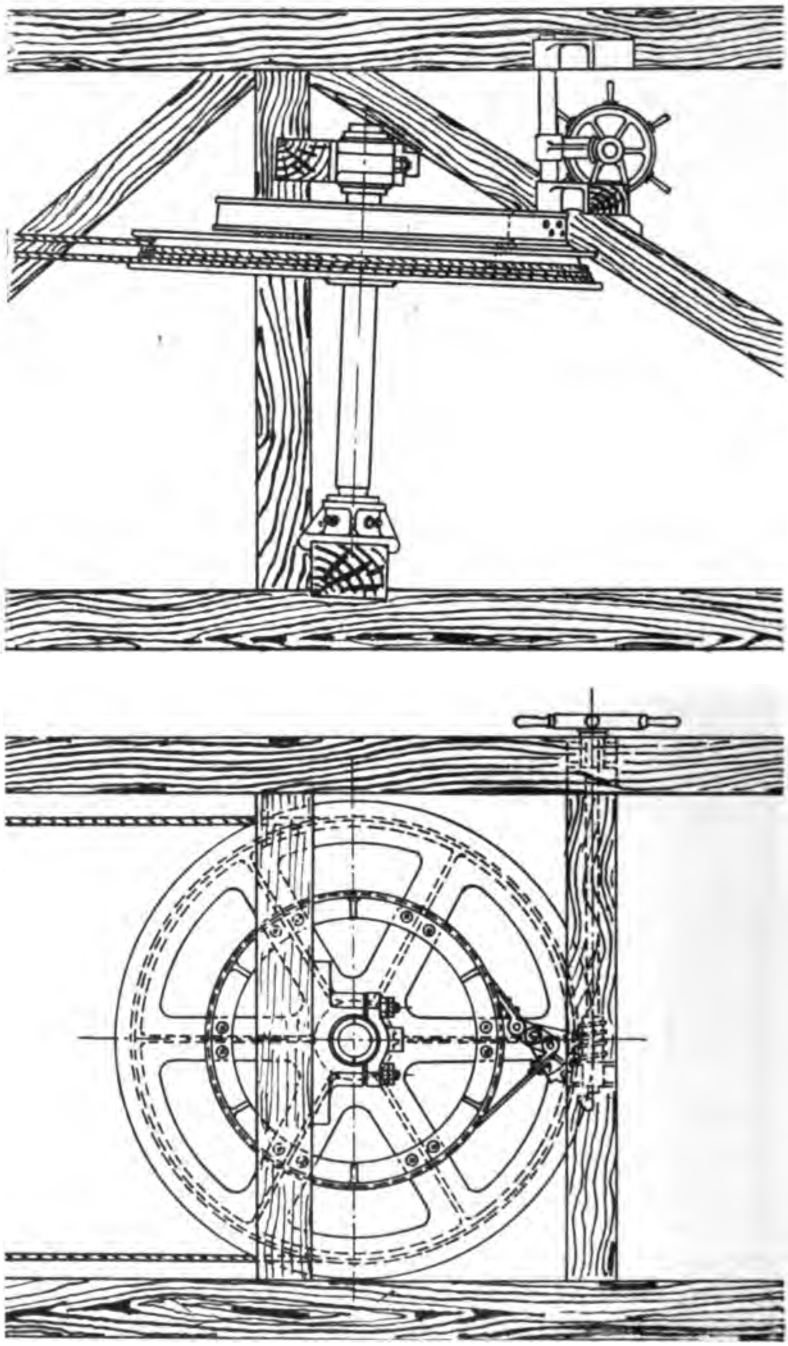


FIG. 190.

SCREW-OPERATED STRAP BRAKE, SUITABLE FOR SELF-ACTING ENDLESS-ROPE INCLINES, MESSRS. J. E. WRIGHT & COMPANY LIMITED.

is the arrangement where one rope is employed with the full and empty gangs attached to its two extremities.

In some cases two separate ropes are employed, and a drum is used instead of a C pulley, one rope coiling on as the other coils off.

Of course it is understood that the principle of self-acting haulage is that the train of loaded tubs, in descending the incline, hauls up a train of a corresponding number of empty tubs. The gradient, therefore, must be such that the weight of the coal can overcome the friction and inertia of all the tubs and the rope, as well as a certain fraction of the weight of the latter.

It will thus be seen that, in self-acting haulage, the important factors are the rolling friction and the gradient.

GRADIENTS FOR SELF-ACTING HAULAGE.

The first consideration, therefore, will be the rolling friction. This is the friction of the tub axles in the pedestals, and the friction between the wheels and the rails. Good appliances and efficient lubrication on the one hand, and care in the laying and maintenance of the road on the other, are consequently matters of considerable importance in this respect.

Various authorities have estimated the allowance to be made under this head at from 32 pounds per ton (one-seventieth of the load) to 80 pounds per ton (one-twenty-eighth of the load).

Whilst the former is probably much too small an allowance, the latter may be somewhat on the liberal side. The late author of this work always adopted this figure; and whilst the present writer quite agrees that it may be excessive, as compared with actual results under favourable circumstances, he also agrees with the late author in recognising the fact that in colliery practice we have to lay ourselves out for unfavourable as well as favourable conditions. It is not good engineering to make our arrangements upon such lines that we are dependent upon everything being in our favour for continuous operation; we must have some force in reserve, and for this reason it will be wise, in estimating for haulage, unless we have actual data to guide us, to make fairly liberal allowances where allowances have to be made, and 80 pounds per ton, or one-twenty-eighth,

is an allowance of this character, and may be taken as applying to the rope as well as the tubs.

CALCULATION FOR SELF-ACTING INCLINES.

Take the weight of the loaded train of tubs, and deduct the weight of the empty tubs and the rope; calculate the total load due to friction, and divide the first result by the second; this gives the base or horizontal measurement of the gradient on which the full tubs at the top will exactly balance the empty tubs at the bottom, together with the rope in the brow. In practice the average inclination will have to be steeper than this, and this is usually provided for by making the top of the incline steeper for a short distance than the calculated gradient, whilst a corresponding length at the bottom is made flatter.

An example at this point will make matters clear: A train or gang of twelve tubs, each weighing 5 cwts. and carrying 10 cwts. of coal, to be jigged in a brow 240 yards long. The rope will be taken as weighing 2 pounds per yard, and the rolling friction, etc., to be taken, in this particular case, as one-thirty-second.

Loaded gang, 15 cwts. × 12 = 180 cwts.	=	20,160 pounds.
Empty gang, 5 cwts. × 12 = 60 cwts.	=	6,720 pounds.
Rope, 240 × 2	=	480 pounds.
Total ...		27,360 pounds.

Divide by 32 for the frictional resistances, 27,360 ÷ 32 = 855.

Loaded gang	20,160
Less empties and rope ...	7,200
	12,960

And 12,960 ÷ 855 = say, 15, or a gradient not flatter than 1 in 15.

The first few yards would be made somewhat steeper than this, whilst the bottom of the brow would be flatter.

From actual practice, under fairly good conditions, self-acting inclines appear to have an average inclination of about 1 in 18.

In exceptional cases self-acting inclines have been worked on even flatter inclinations. One instance, at least, has come under the writer's notice, where the inclination at the top was 1 in

26, with no places steeper than 1 in 23, and two lengths of 1 in 30 and 1 in 35 respectively, but in this case things were cut rather fine.

The endless-rope system can be and is applied on self-acting inclines, and with care in laying out the system, and regular and equal spacing of the tubs, the results are very pleasing. This system can be got to work on a somewhat flatter gradient than is possible with the ordinary arrangement, the rope not only becomes a balanced arrangement, but the rope friction is reduced. (*See fig.* 190, *page* 334.)

HAULAGE BY MECHANICAL POWER.

By far the greater portion of the underground haulage, however, has to be effected with the aid of power, which may take the form of steam hauling engines, either on the surface or underground, compressed air engines, or electric motors. Whatever form the power may take, the system will either be direct rope, main-and-tail rope, endless rope, or endless chain.

DIRECT ROPE HAULAGE.

This system, in its simplest application, consists of a single rope, coiling and uncoiling on a drum, actuated by one or other of the forms of power named. The idea is that the train of wagons is hauled up the incline to the top, where a train of empties are attached to the end of the rope in place of the full wagons.

The gradient must be sufficiently steep to allow the empties to run down the brow, drawing after them the rope, and incidentally revolving the drum, which may be thrown out of gear, or in flat places the drum may be assisted by the engine.

The inclination necessary for this must be at least steeper than about 1 in 28. Only a single road is required, and, to reduce both the friction and wear and tear of the rope, rollers are fixed between the rails every 15 or 20 yards. (*See fig.* 191, *page* 338.) These must be kept in order and regularly lubricated. If the brow is not quite straight—and all haulage planes *should* be straight, unless there is some very good reason for deviating from a straight line—rollers are also fixed at the side of the road, in the bend or curve, to obviate friction of the rope on the side of the roadway.

A modification of this system is the double-rope system, one ascending with the full gang, whilst the other is being drawn down by the empty gang. In this system a double road is required from end to end of the brow—at least this is the most desirable arrangement. A single road, with a pass-by arrangement in the middle, is liable to lead to accidents. A good modification

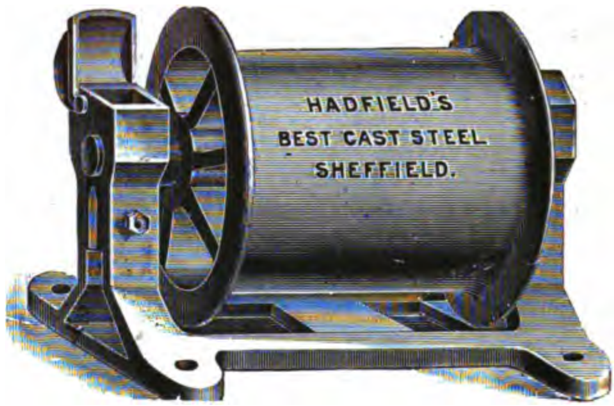


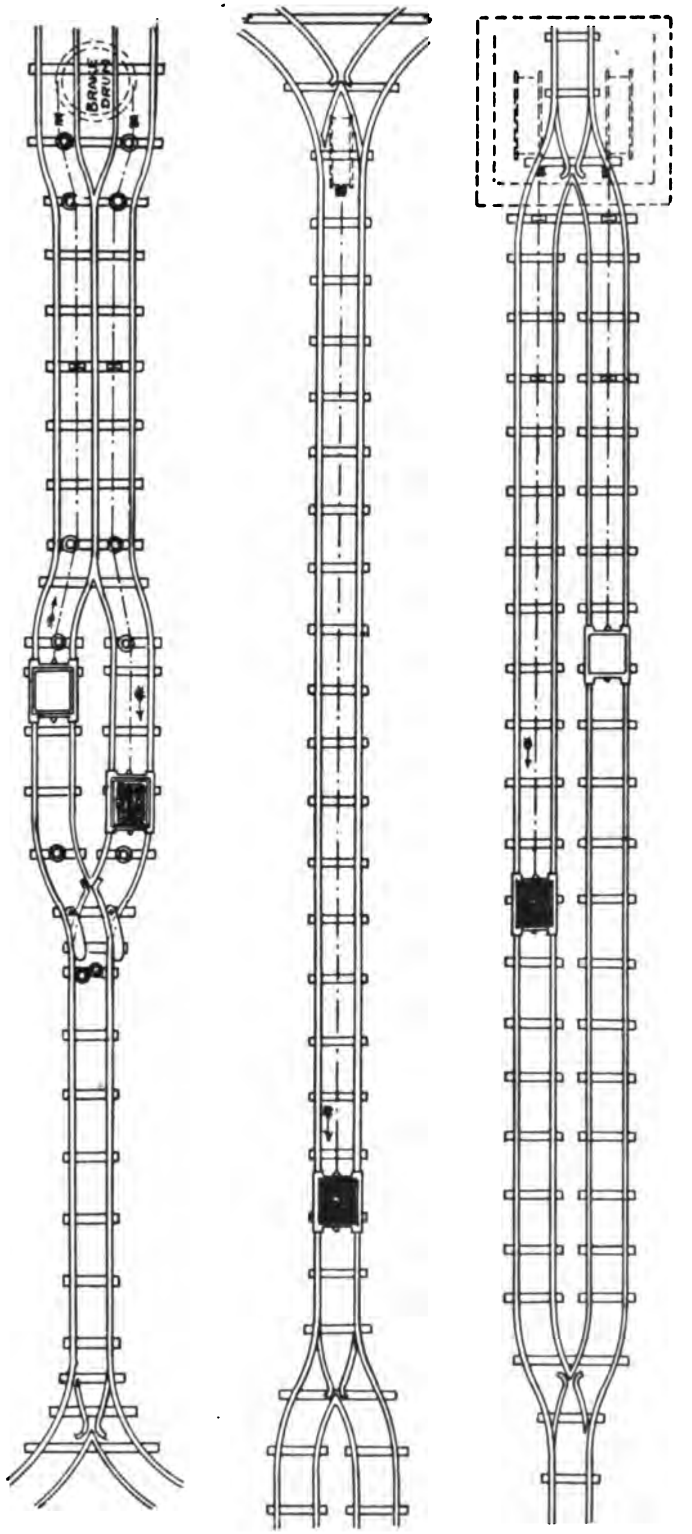
Fig. 191.

Steel Roller for Haulage Planes.

is the three-rail system, which is also adopted in self-acting inclines. (*See fig.* 192, *No.* 1.) Three rails are laid down the upper portion of the brow, and similarly in the lower portion. The middle rail forks into two some distance above the place where the two gangs will pass, and for a suitable distance down brow the rails are laid as a double road. This obviates the necessity for points in the brow at the passing place, and collisions are impossible. Of course the middle rail also forks at the top and bottom of the incline, so as to make two roads.

Direct haulage means an intermittent delivery of coal, and necessitates a fairly high speed. The system is worked to speeds as high as ten or even fifteen miles per hour. These high speeds in underground haulage are objectionable, and the necessity for high speed constitutes one of the disadvantages of direct haulage.

Where steam or compressed-air engines are employed, they may be either direct or geared, generally the latter. The engines should be a pair coupled, with their cranks at right angles in the usual way. The drum may be loose on the shaft,



1 2 3

Fig. 192.—Showing Methods of Laying the Rails on Inclined Haulage Roads for Direct Haulage or Self-Acting Inclines.

with an efficient clutch, to throw it in or out of gear—preferably a friction clutch. A brake must be fitted, and the engines should be reversible.

The illustration (fig. 193) gives a general idea of an alternative arrangement of the engine.

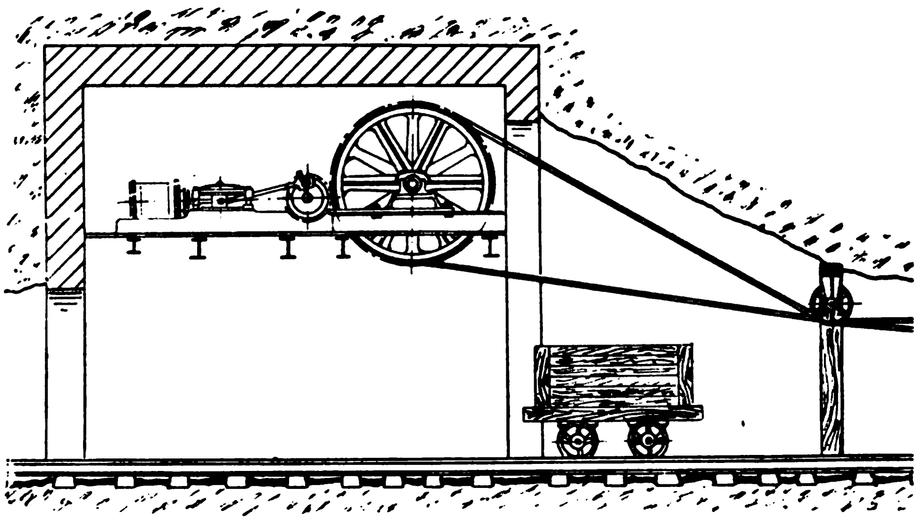


Fig. 193.
ARRANGEMENT OF HAULING ENGINE.

For moderate speeds and steep seams a geared engine wil generally be preferred. A pair of coupled horizontal engines, with a pinion on the crank shaft gearing into a spur wheel on the drum shaft. The friction clutch, brake (on the drum), and reversing gear will be provided as before.

TO CALCULATE THE POWER FOR DIRECT SINGLE-ROPE HAULAGE, SIZE OF ENGINES, ETC.

This can best be made clear by means of an example. We propose to calculate, first, the horse power on the rope to deal with 500 to 600 tons per day of 8 hours, up an incline of 1 in 5, 1000 yards long; haulage speed not to exceed 8 miles per hour.

Eight miles per hour = 704 feet per minute—we shall adopt, for convenience, a speed of 700 feet per minute:—

600 tons $\div$ 8 = 75 tons per hour.

3000 feet $\div$ 700 = say, 4·3 minutes per run, that is,

4·3 minutes hauling,
4·3 minutes running back,

8·6 minutes,

and with a reasonable allowance for changing tubs, say, a total of 12 minutes, or 60 $\div$ 12 = 5 gangs of loaded tubs per hour. 75 tons $\div$ 5 = 15 tons of coal on the rope at each run.

The load on the rope is due partly to gravity—which we may calculate by dividing the gross weight of tubs, coal, and rope by the gradient (in this case by 5 for a gradient of 1 in 5)—and partly to frictional resistance, which we shall take as one-twenty-eighth for the tubs and the rope. The rope for this load will weigh about 6 pounds per yard.

Load due to gravity :—

Coal, 15 tons...	33,600	pounds.
Tubs (half the weight of the coal)	16,800	„
Rope, 1000 × 6 equals...	6,000	„
Total	56,400	„

divide by 5 = 11,280 pounds.

Load due to friction—that is, the gross weight $\div$ 28 :—

56,400 ÷ 28 equals ...	2,014	pounds.
Add load due to gravity,	11,280	„
	13,294	„

Multiply by the haulage speed of 700 feet per minute, and divide by 33,000 : $\dfrac{13{,}294 \times 700}{33{,}000} = 282$ horse power.

This figure—282 horse power—represents the energy which must actually be delivered to the haulage rope. To arrive at the power required in the engine, the indicated horse power, a further calculation is necessary.

The late author had a very simple rule, founded upon his own extensive practical experience of colliery engineering, and although it may appear to some of our readers somewhat empirical it is still reliable, and the present writer has no hesitation in now adopting it.

The rule in question has reference to the allowances which must be made to cover the losses between the energy developed

in the cylinder and the haulage or winding rope—in other words, the useful effect of the engine and gearing. His practice was to add 50 per cent to the calculated power required. In the above example, where 282 horse power must be transmitted to the haulage rope, he would have added 181, making a total of 463 indicated horse power. This means a combined efficiency for the engine and gearing of 66 per cent, and actual experience shows this to be a reasonable and fair allowance.

In the above example, to show how we arrive at the size of a pair of engines for the work required, assume an average effective steam pressure of, say, 50 pounds and a piston speed of 400 feet per minute—

$$13{,}294 \times 700 = 9{,}305{,}800 \text{ foot pounds per minute.}$$
$$\text{Add 50 per cent} = 4{,}652{,}900$$

Divide by 2 (two cylinders) 13,958,700

equals 6,979,350 foot pounds per minute;

and $\frac{6{,}979{,}350}{400 \times 50} =$ say, 349 square inches area of each cylinder, or, in round numbers, 21 inches diameter.

The stroke would be about twice this, or 3 feet 6 inches, and the engine would run at an average of $\frac{400}{3 \text{ feet } 6 \text{ inches}} \times 2 =$ say, 57 revolutions per minute.

A drum of 8 feet diameter, or 25 feet circumference, would have to make $\frac{700}{25} = 28$ revolutions per minute to give the required rope speed, which would mean gearing in the proportion of about 2 to 1.

With lighter loads, or flatter gradients, the drum would perhaps be direct-coupled—that is, mounted on the crank shaft of the engine.

CALCULATIONS FOR ENDLESS-ROPE HAULAGE.

It will be interesting to repeat this calculation, with the same conditions, but for endless-rope haulage instead of direct haulage. The result will be striking, and clearly prove the great advantage of the endless-rope system.

Taking again, then, a haulage plane 1000 yards long, inclination 1 in 5, and 500 to 600 tons per day of 8 hours,

$600 \div 8 = 75$ tons per hour. A fair speed for endless-rope haulage is from $1\frac{1}{2}$ to 3 miles per hour. We shall assume a speed of 2 miles per hour, or, to keep to convenient figures, 150 feet per minute, which is slightly less: 3000 feet $\div 150 = 20$ minutes, the time required for the lowest tub on the rope to travel to the top of the haulage plane. This may be expressed in another way—the rope will discharge its full capacity of coal 3 times per hour, and $75 \div 3 = 25$ tons of coal on the rope at one time.

One important feature in endless-rope haulage is, that we have only to provide power to haul the coal, plus power to cover the friction of the system.

There is no necessity to provide power to haul the tubs or the rope (other than the friction), because the system, so far as the tubs and rope are concerned, is a balanced one.

For every pound weight of rope ascending there is a pound descending. For every tub ascending there is, if the tubs are properly spaced, a tub descending:—

Load due to the gradient—25 tons $\div 5 = 5$ and multiplied by $2240 = 11{,}200$ pounds.

Load due to friction, taken as before, at one-twenty-eighth:—

Coal, 25 × 2240 equals... ...	56,000 pounds
*Tubs, equal to the coal... ...	56,000 pounds
Rope, 2000 yards × 6 pounds per yard	12,000 pounds
	124,000 pounds
Divide by 28, equals	4,429 pounds
Add load due to gradient ...	11,200 pounds
	15,629 pounds

$$\frac{15{,}629 \times 150}{33{,}000} = \frac{2{,}344{,}350}{33{,}000} = \text{say, 71 horse power on the rope.}$$

It will be seen that this is practically one-fourth of the power required for direct rope under exactly the same conditions.

It might be asked, why the same strength of rope is taken in both cases, although the weight of coal is 10 tons greater in the latter. The explanation is simple. In the former case the

* Since one tub equals half the weight of the coal, and there are as many empty tubs on the rope as full ones.

speed is high, and the variations of load due to this and to overcoming inertia are greater; in the latter the speed is slow and the load more uniform.

Proceeding on the same lines, and taking the same average effective steam pressure of 50 pounds, but 350 feet per minute piston speed (as the engine will be smaller):—

	2,344,350 foot pounds per minute,
Add 50 per cent ...	1,172,175
	3,516,525

divide by 2 for two cylinders=1,758,262, and $\frac{1,758,262}{350 \times 50}$ = say, 100 square inches area, or practically 12 inches diameter. The stroke will be 2 feet; the revolutions of the engine $\frac{350}{2 \times 2} = 87{\cdot}5$ per minute, and with a rope wheel 25 feet circumference $\frac{150}{25} = 6$ revolutions per minute; proportion of gearing $14\frac{1}{2}$ to 1.

ATTACHMENT OF THE TUBS TO THE ROPE IN DIRECT HAULAGE.

In simple direct haulage the tubs or boxes are attached to the extremity of the haulage rope, which, for this purpose, is provided with some suitable form of capping. The tubs are attached in long gangs, and every precaution has to be taken to prevent any or all of them breaking loose. The breaking away of the whole gang of wagons is, of course, a matter of the haulage rope breaking, or the attachment to the end of the rope breaking or otherwise becoming detached. With regard to the former—breaking of the rope—the remedy is apparent, the ropes should be sufficiently strong, with a proper margin of safety; a strength equal to seven or eight times the maximum working load is not any too much to allow as a factor of safety.

The ropes must be carefully examined for signs of undue wear, and must be discarded before the strength is seriously diminished. The cappings must be properly made, and the hooks or other fastenings to connect the rope to the drawbar

of the wagon must be so constructed that accidental detachment is impossible.

The most fruitful cause of accident is the breaking of the short coupling chains used to connect the several tubs together

FIG. 194.

in the train. The best possible arrangement the writer is acquainted with for this purpose is illustrated in figs. 194 and 195, designed and used by the writer's friend, Mr. F. L. Ward, of the Bradford Colliery, Manchester, whose name has been intro-

FIG. 195.

duced elsewhere in connection with some notes on the capping of winding ropes. Mr. Ward was determined to put an end to accidents caused by coupling chains breaking, and as the inclination of the mines at his colliery is rather steep, this was

a matter of urgency. He overcame the difficulty by dispensing with coupling chains altogether, and substituting the double-ended steel hook shown in the illustration. It is used in conjunction with the special arrangement of drawbar, fig. 196,

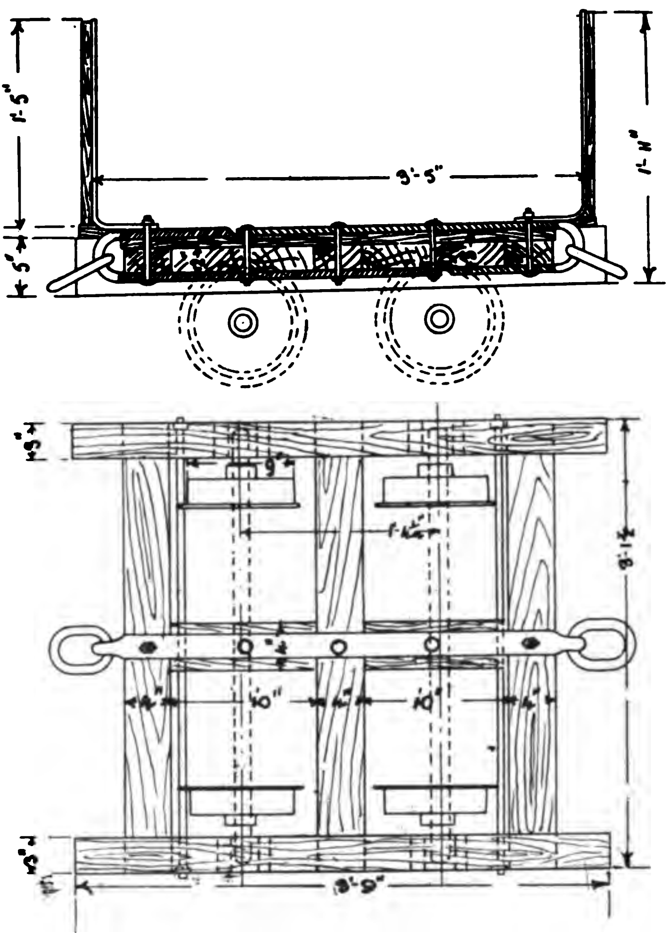


FIG. 196.

in which it will be seen the drawbar consists of two straps forming a D at either end with one loose link in each. The coupler is quickly and easily connected and disconnected, and there has not been a single instance of tubs breaking away since these were introduced.

The coupler, as used at Bradford Colliery, with tubs of seven hundredweights' capacity, weighs 8 pounds; the overall length is 14 inches; the round bar forming the middle portion measures $1\frac{3}{16}$ inches diameter.

Where the ordinary form of coupling chain is used a good plan is to pass a chain from the end of the rope to the back end of the last tub. If any intermediate coupling link breaks or becomes disconnected the chain prevents the tubs running back.

With the same object in view a "devil" or "bobby" is sometimes employed. The appliances upon which these high-sounding and dignified titles have been conferred consist of an

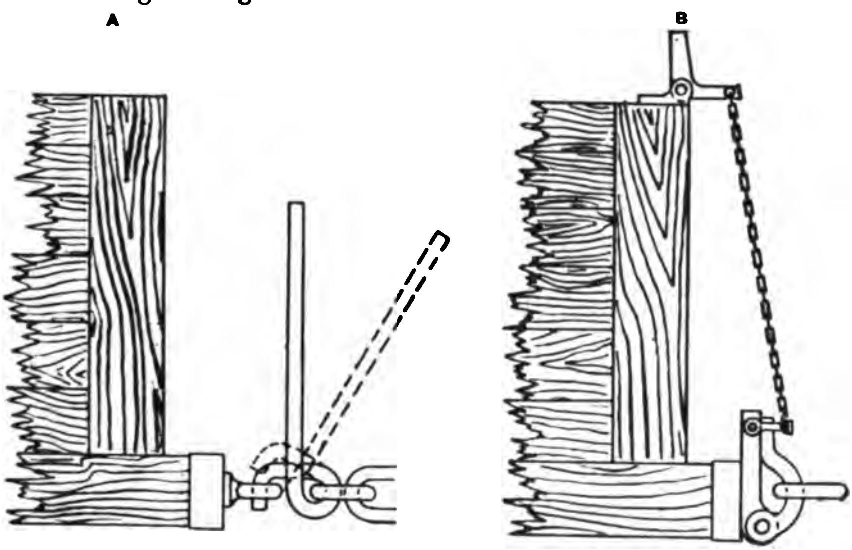


FIG. 197.

iron bar or sprag, with a forked end, which is attached either to the back of the last tub or, in some cases, to the axle of the last tub. The fork end trails along the ground, and, in the event of the rope breaking, the coupling links giving way, or the tubs tending to run back from any other cause, the forked end sticks into the floor or against a sleeper, and prevents the tubs running back.

Various arrangements are in use for the purpose of automatically detaching the gang from the rope at the landing place. Most of these appliances are sufficiently simple; but

they should be so contrived that it is impossible for them to come into operation at the wrong time. For example, there is the arrangement illustrated in B, fig. 197 (*see page* 347), with the projecting lever above the top of the tub. The intention is that on arrival at the landing place the projecting lever strikes a bar placed across the roadway, thus releasing the tubs from the rope. Now this arrangement, no doubt, acts as it should do at the landing place; but it will be evident that it *might* act in the middle of the brow, with disastrous results. A broken bar in the brow might become displaced, and if low enough to come in contact with the lever it would release the tubs. In the writer's humble opinion any contrivances for detaching tubs or cages from ropes which may come into action at the wrong time are undesirable, and the arrangement, shown in fig. 197, to his mind, is altogether too risky.

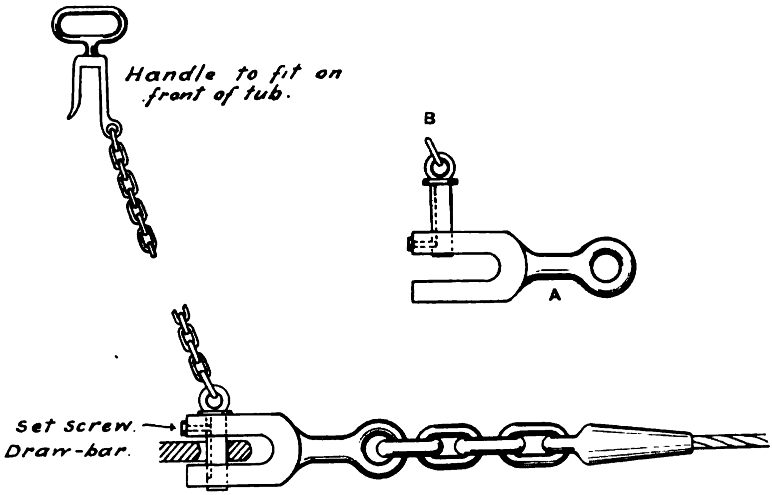


FIG. 198.

Another form of hook, operated by hand, is shown in fig. 197 (A). (*See page* 347.)

At Messrs. William Ramsden & Sons' Shakerley Collieries, Tyldesley, Lancashire, an arrangement is used not unlike the one shown in fig. 197, except that it is operated by hand, and there is no risk of its coming into operation at the wrong moment. Fig. 198 will make the action of the appliance clear. The rope is attached to the drawbar of

the tub by means of a shackle (A), a loose pin (B) being passed through the hole in the end of the drawbar. This pin can be raised sufficiently to free the drawbar, but is prevented from lifting entirely out of the shackle by means of a stud or setscrew, the end of which fits in a slot in the pin. A short, light chain, terminating in an iron handle, is attached to the pin, the handle being hooked in a convenient position to the front of the tub.

The brow up which the tubs are hauled forms an angle with the shaft level, and a pulley is fixed at the top to divert the direction of the haulage rope, which comes along the level from an engine on the surface. The train of tubs reaches the top of the brow with a velocity sufficiently great to carry them to within a short distance of the pit bottom, but before reaching the pulley an attendant, stationed at the top of the brow, seizes the handle attached to the chain as the front tub runs past him, draws the pin, and frees the rope. This contrivance is very simple, it is easily manipulated, and at the Shakerley Collieries, where it has been in use for some years, it has proved entirely satisfactory, and has never been the cause of an accident. Personally, the writer prefers this arrangement; it is much better than the automatic contrivances, which may become detached at the wrong time.

MAIN-AND-TAIL ROPE HAULAGE.

The main-and-tail rope system is adapted for mines with a varying gradient, where the average is not sufficiently steep to enable the empty tubs to run back and draw the haulage rope. It is also adopted in mines where the conditions are such that it would be costly and difficult to maintain a double road for endless-rope haulage; indeed, one arrangement of endless-rope haulage, in which the tubs are attached to the rope in gangs, has much in common with the present system.

In principle the main-and-tail system is one in which two ropes are employed—one, the main rope, for hauling the loaded tubs or wagons towards the shaft; and the other, the tail rope, for hauling the empties back. The tail rope is a much lighter rope than the main rope, but it is twice the length of the latter, since it has to pass from the hauling engine to the farthest extremity of the haulage system, round a pulley, and,

when the tubs are at the out-bye end of the system, nearest the shaft, back again to the train of tubs.

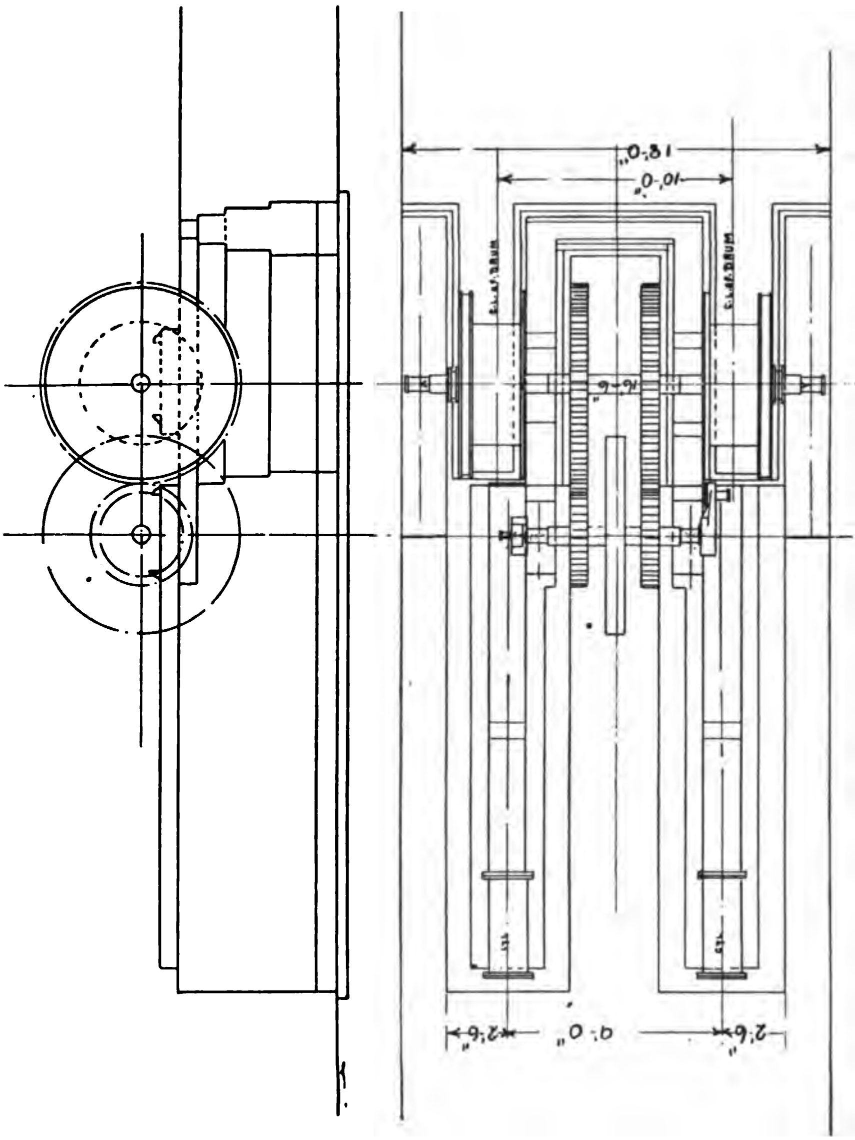


FIG. 199.—ARRANGEMENT OF ENGINES FOR MAIN-AND-TAIL ROPE HAULAGE.

The hauling engine for main-and-tail rope systems, therefore, requires two drums, one for each rope. Both are mounted loose upon the drum shaft, with clutch arrangement to throw

either of them in or out of gear. Fig. 199 represents an arrangement of hauling engine with two drums, for main-and-tail rope haulage. Another arrangement is one with the drums on separate shafts. The crank shaft of the engine carries a pinion which gears into both of the spur wheels, one on each drum shaft. Each drum, in both arrangements, is provided with an adequate brake.

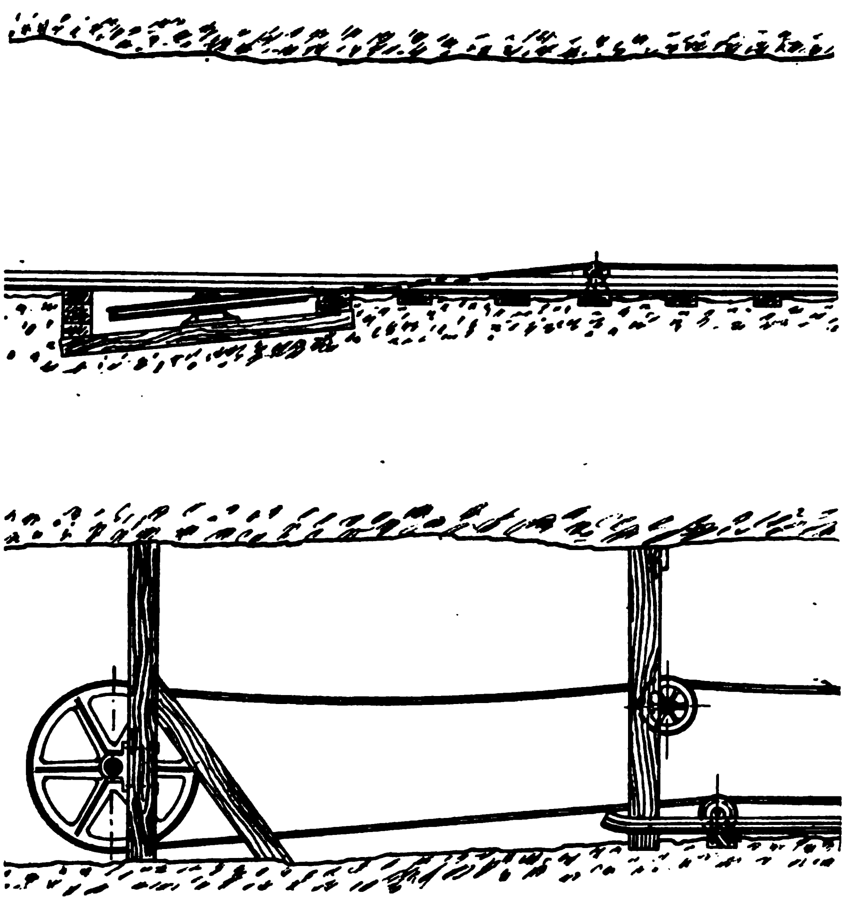


FIG. 200.
SHOWING TWO ARRANGEMENTS FOR THE TAIL-ROPE RETURN PULLEY.

In hauling the full tubs out the main-rope drum is in gear and the tail-rope drum runs loose, paying out the tail rope, the extremity of which is, of course, attached to the rear end of

the train of wagons. On the return trip, hauling the empty train in-bye, the main drum is out of gear, and the tail-rope drum is driven by the engine. As the empties are hauled back in-bye, the main rope, attached to the rear end, is drawn off the drum, and taken into the far end in readiness to haul out the next gang of full wagons.

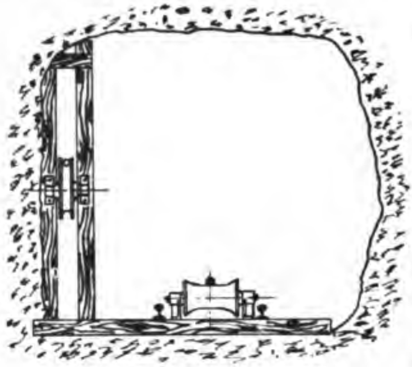


FIG. 201.
SHOWING PULLEYS IN MAIN-AND-TAIL ROPE HAULAGE ROAD.

Although the engines are usually equipped with reversing gear, it will be seen that they may run ordinarily in the same direction, whether hauling full or empty tubs; if both ropes coil on the drums the same way, it is then merely a matter of throwing one or the other out of gear and running the engine in the same direction. The reversing gear is usually applied, however, and the engines, as a rule, consist of a pair coupled.

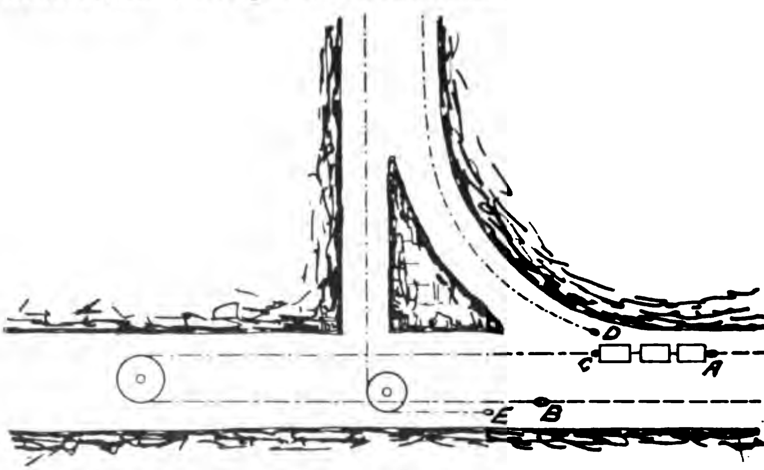


FIG. 202.

Fig. 200 (*see page* 351) shows two arrangements of the return pulley for the tail rope at the far end of the system. One side of the tail rope is carried by means of pulleys at the side of the

road, out of the way, since that side merely forms a connection between the tail-rope drum and the return pulley. The arrangement of carrying pulley is shown in fig. 201.

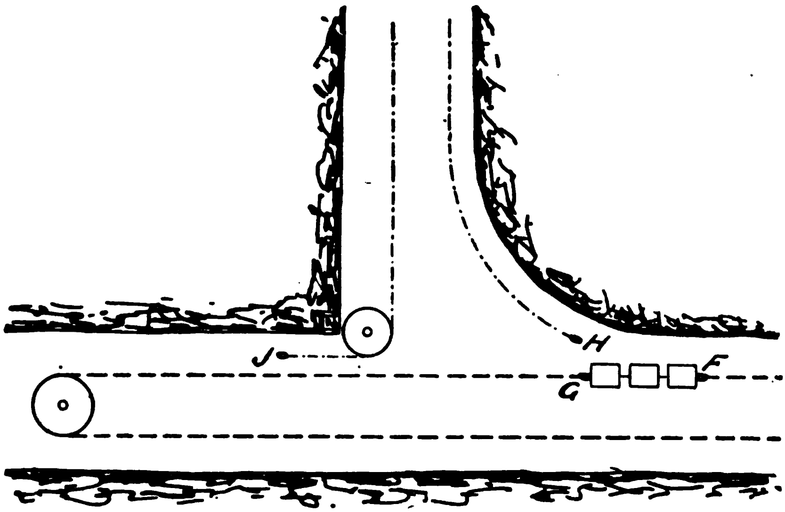


FIG. 203.

Branch roads are worked in several ways, the more general methods being illustrated in figs. 202, 203, and 204. In fig. 202 the ropes are arranged so that the gang may be diverted when reaching the branch road. Of course, at the end of each branch road a return pulley is provided (*see fig.* 200,

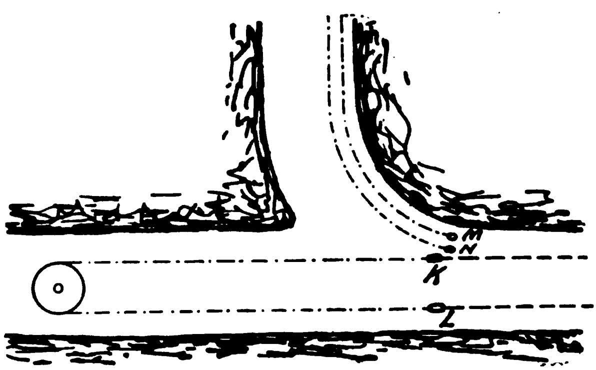


FIG. 204.

page 351) and a branch rope twice as long as the branch road, with shackles at the ends for connecting with the main

road ropes. (*See figs.* 205 *and* 206.) On arriving at the branch road (fig. 202, *see page* 352) one end of the branch rope D is attached to the end of the train of tubs, taking the place of C. By means of the shackles E and B are connected, leaving the section of rope on the main road—to the left—cut out of action. The engine is set in motion again, and

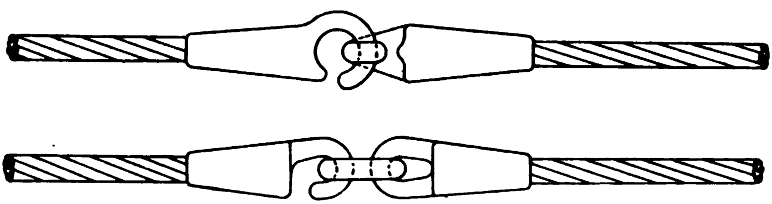


FIG. 205.

the gang (in this direction, of course, empty) is hauled into the branch road, from the far end of which the next full gang is withdrawn. On reaching the main road the rope is stopped, and the connections rearranged as at first. It will be understood that the lengths of the ropes are so proportioned that

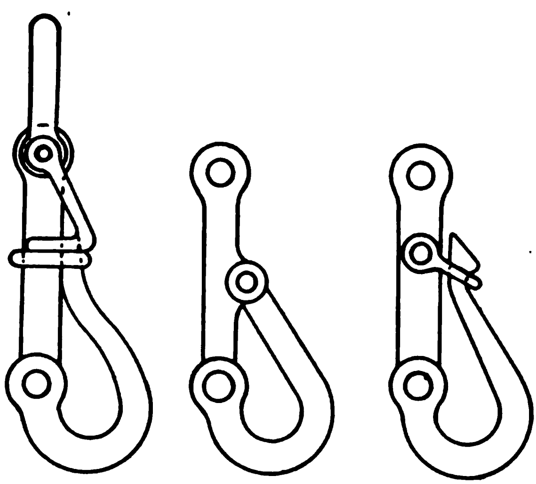


FIG. 206.

the shackles are all in convenient proximity at the proper time and place. A winch is, however, generally provided in this particular arrangement to assist in drawing up the ropes for connecting.

Fig. 203 (*see page* 353) shows another arrangement, in which the effect is simply that of inserting an extra length of rope in

FIG. 207.

the tail rope between the end of the tubs and the end of the main road tail rope; thus, **G** is connected with **J**, and **H** takes the place of **G** at the end of the gang; the motion is then resumed, and the tail rope remains a continuous but increased length, so as totake in the branch road. The use of a winch in this case is dispensed with.

The third method, illustrated in fig. 204 (*see page* 353), is, perhaps, the simplest arrangement, and saves time in haulage. The changing of the ropes is carried out whilst the train of tubs is at the pit; indeed, whilst the ropes at the pit are being disconnected from the loaded train, and attached to the empty train of wagons ready for the in-bye journey, the change has been effected at the branch road, so that the haulage may proceed without further stoppage until the journey is completed. The illustration will make the connections clear. The length of the main road ropes is so arranged that when the tubs are at the pit the two shackles **K** and **L** are in the relative positions shown. They are both disconnected, and **M** and **N** coupled up.

Fig. 207 (*see page* 355) shows the arrangement of pulleys for taking the ropes round the curves.

The speed of the rope for main-and-tail haulage, like direct rope, is fairly high, from eight to ten or even fifteen miles per hour, and also, as in the case of direct haulage, the delivery of coal is irregular and intermittent. We have already shown by calculation that for the same output, under given conditions, the expenditure of energy for direct rope haulage is four times as great as for endless-rope. A similar calculation would demonstrate that main-and-tail rope haulage calls for about four times the power necessary to deal with the same load, under the same conditions, with endless-rope. The explanation is simple; in the case of direct haulage and main-and-tail rope haulage not only have we a larger unbalanced load, but that load has to be moved at a much higher speed.

ENDLESS-ROPE HAULAGE.

There are, no doubt, cases in which one system of haulage will give better results than another, but there can be little doubt that the system which is more universally adaptable, and which offers the greatest advantages, is the endless-rôpe system. The speed is slow, wear and tear less, liability to accident less,

and when an accident does occur it will be admitted that the consequences are more serious with high-speed haulage than with slow-speed. The delivery of coal is regular and uniform, the power required for a given output is less, and the hauling engines smaller and therefore less costly; it is more elastic than other systems of mechanical haulage; that is to say, it can be applied successfully under widely differing conditions. The writer is personally acquainted with endless-rope haulage, not only in flat mines, and in mines with a varying or undulating gradient, but in mines at different inclinations, from nearly flat to the extreme case of a mine with an average inclination of between 40 and 45 degrees from the horizontal.

In its simplest application the endless-rope system consists of a rope practically twice the length of the haulage plane, with its ends, of course, spliced together. This rope is carried along the haulage road, which is laid with a double line of rails, and motion is imparted to it continuously in one direction, so that one side moves away from, and the other towards, the shaft, and the two sides thus become available for simultaneously taking empty tubs into the workings and bringing full ones out. The tubs are attached to the rope either singly or in sets of two or three, and to give the best results they should be equally spaced along the rope, and as many full tubs on one side as empties on the other. The motive power may be in the mine or on the surface, and may take the form of steam, compressed air, or electricity, the same forms of energy being, of course, also applicable with the other systems of haulage described.

Formerly the hauling engines were placed underground, a practice, to some extent, still adopted. Latterly, where steam is applied for haulage, the practice has been to erect the hauling engines on the surface, conveniently near to the shaft, and transmit the motive power to the haulage gear by means of an endless driving or strap rope—that is, an endless rope employed for actuating the haulage gears only, not taking any part in the actual haulage of the tubs.

Some excellent examples of such arrangements, as carried out at important modern Lancashire collieries, are shown in figs. 208, 209, 211, 212, and 213. (*See sheets* 6 *and* 7, *between pages* 356 *and* 357.) A description of these will sufficiently

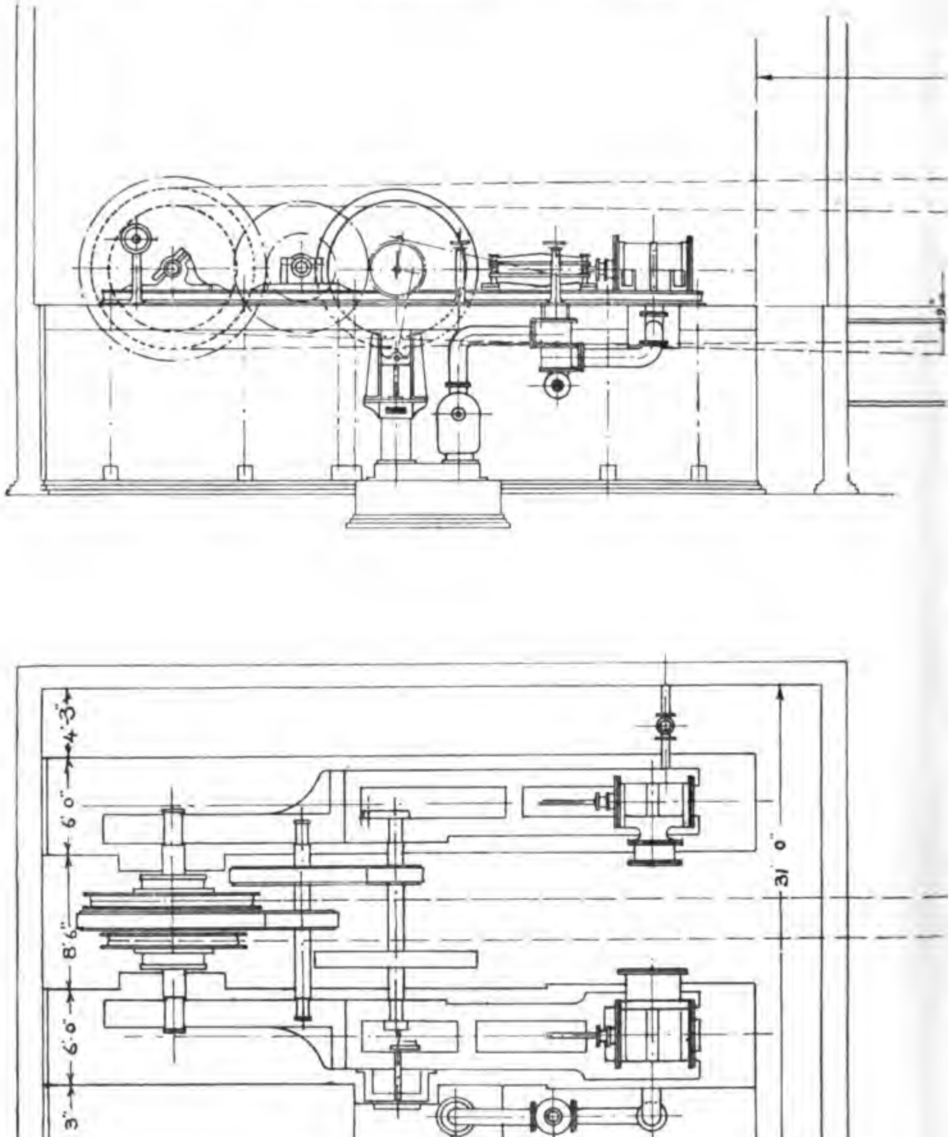


FIG. 214.

PLAN AND ELEVATION OF A CROSS-COMPOUND CONDENSING ENGINE, FOR ENDLESS-ROPE HAULAGE.

(*See opposite page.*)

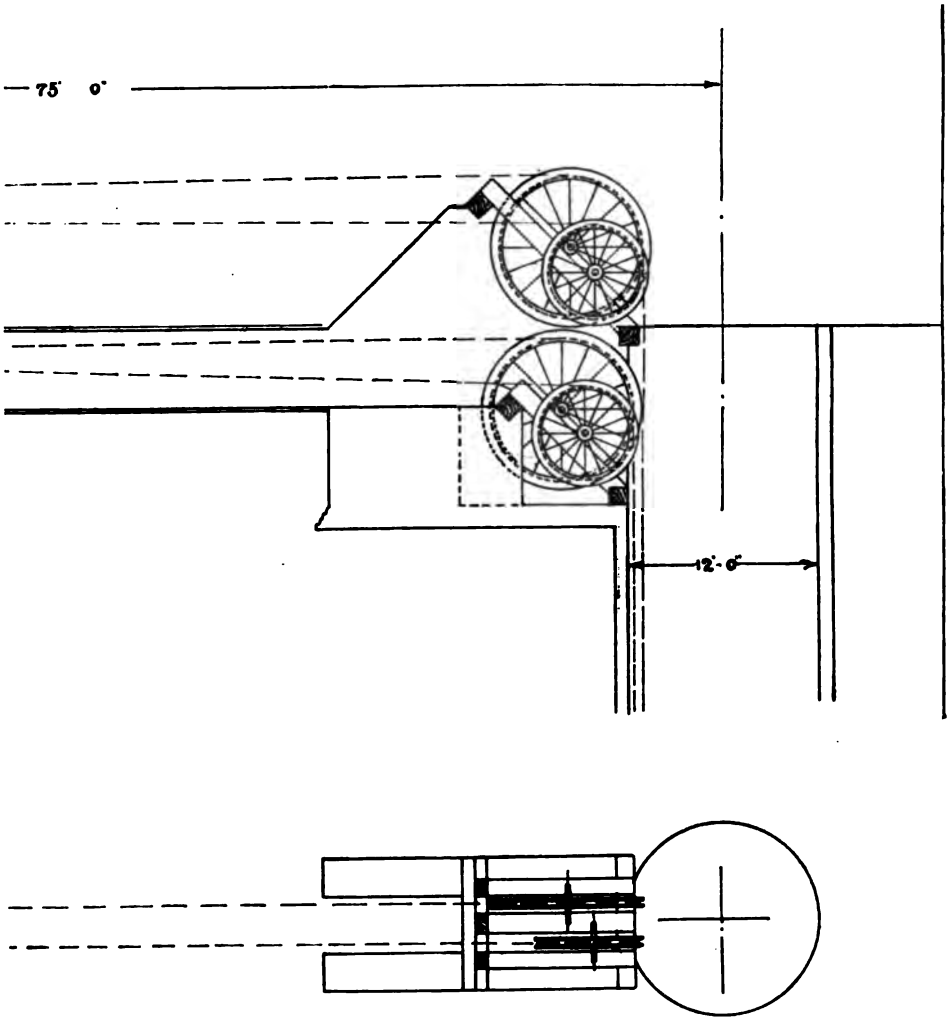


Fig. 214.

Showing the arrangement of Pulleys at the Pit-top. (*See opposite page.*)

Messrs. John Wood & Sons Limited, Wigan.

explain the system generally. Referring to figs. 208 and 209 (*see sheet* 6, *between pages* 356 *and* 357), we have a section showing the hauling engines on the surface, the pulleys at the top of the shaft, the pulleys at the bottom of the shaft, and two vertical shafts with haulage pulleys, clutch gear, and brakes for working the two haulage planes shown in the plan. (*See fig.* 209, *sheet* 6.) The engine is a cross compound condensing engine, with a pinion on the crank shaft gearing into a spur wheel, on which there is another pinion gearing into a wheel on the rope-wheel shaft. The course of the strap rope can easily be followed in fig. 208 (*see sheet* 6), passing over the pulleys at the top of the shaft down to the bottom, where, in this particular case, there was some little difficulty; it was not possible to make room for a pulley of sufficiently large diameter, and the rope had to be deflected into the horizontal direction by means of the arrangement shown, which consists of a strong framework carrying six small pulleys, three for each rope. This arrangement is, of course, not so good for the rope as a larger pulley, but failing the convenient erection of a single large pulley for each side of the rope, the plan shown is a good illustration of the way in which such a difficulty can be got over.

The rope now passes to the upper pulley keyed on the first vertical shaft (*see fig.* 208, *on sheet* 6), round which it takes three or four turns and then passes to the second vertical shaft, and finally to the return pulley and tension carriage shown on the extreme left. It will thus be seen that this rope is simply a means of transmitting power, and does not take any part in the actual haulage of the tubs.

The idea is that the engine, and therefore the two vertical shafts, shall run continuously, or nearly so, the haulage pulleys—one on each shaft—being thrown in and out of gear by means of friction clutches as desired, neither, however, interfering with the other.

From the larger drawing of the vertical shaft, which will be found on the right-hand lower corner of sheet 6, the reader will be enabled to follow the action of the arrangement without difficulty.

The strap rope from the engine passes two or three times round the upper pulley, which is keyed to the shaft. Immedi-

ately below is the sliding collar, operated by the handwheel and screw, shown on the right, for throwing the haulage pulley in and out of gear. The sliding collar, as it is raised or lowered, operates through the links and levers upon right and left-handed screws, which expand or contract the friction blocks, more clearly shown on the large drawings, figs. 215 and 215A. (*See sheet* 8, *between pages* 360 *and* 361.)

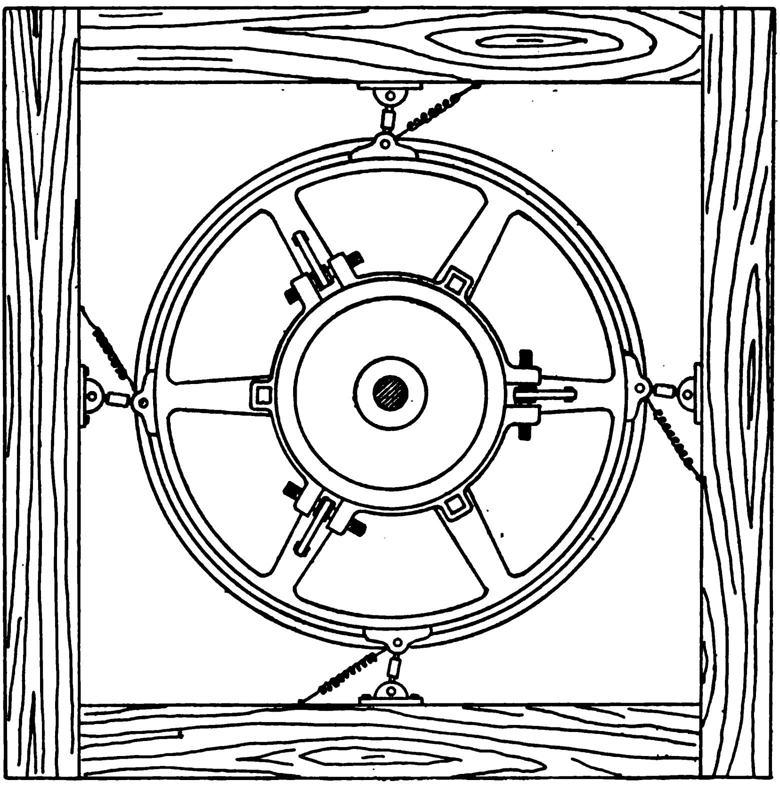


FIG. 216.

PLAN OF ENDLESS-ROPE HAULAGE GEAR, WITH FISHER & WALKER'S FRICTION CLUTCH AND AUTOMATIC RETAINING BRAKES.

It will be observed that above the haulage-rope pulley (*see fig.* 210, *on sheet* 6, *between pages* 356 *and* 357) there is a ratchet arrangement with pawls. The object of this is to prevent the reversal of the rope, which would allow the full tubs to run back, when the pulley is thrown out of gear. The vertical shaft in this instance, as will have been observed from the

drawings on the same sheet, is applied to a brow or incline; it is therefore necessary to make some such provision as that indicated, which allows the pulley to revolve in the proper direction, but prevents its reversal.

An ingenious and effective arrangement for the same purpose is shown in fig. 216. (*See page* 361.) In this illustration a plan view of the vertical shaft is presented, showing Fisher & Walker's friction clutch, and also the retaining brakes to prevent reversal of the rope. It is the latter part of the arrangement to which we desire to call attention. It will be observed that the rope pulley, which has a brake ring cast with it, is enclosed within a strong timber framework, which must be of substantial construction and well backed to prevent springing. Four brake blocks, carried by short arms from brackets on the timbers, are lightly pressed against the brake ring under the influence of light springs. The direction of rotation of the rope pulley is counter clockwise, and it will be noticed that the arms carrying the brake blocks are not perpendicular to the timbers, but slightly inclined in the direction which tends to prevent their coming into action. Immediately the friction clutch is operated, however, to throw the pulley out of gear, and the load on the rope tends to reverse the direction, the brakes tighten up, being spragged against the brake ring by the inclined arms, which absolutely prevent the slightest backward movement.

The writer is familiar with this arrangement working in connection with a long endless-rope haulage plane, *with an average gradient of about 40 degrees from the horizontal*, portions of the plane being over 45 degrees from the horizontal. When the friction clutch throws the pulley out of action, there is not the slightest appreciable reversal of motion.

Just a word at this point with regard to the tension carriage. It will be seen that the return pulley is mounted in a framework carried on rollers running upon elevated rails, and that the necessary tension for taking up slack rope is provided for by means of a weight, hanging vertically, attached by a chain to the pulley carriage. It may be said here, once and for all, that this is the correct and proper method of providing tension for an endless rope. The arrangement represented in fig. 217 is, no doubt, ingenious and well constructed, but for the purpose it is intended for it is deplorably bad, and ought *never*

to find a place in any colliery where good engineering is desired. It enables an unknown and unyielding strain to be put upon the rope, and is quite as bad as working a boiler with neither

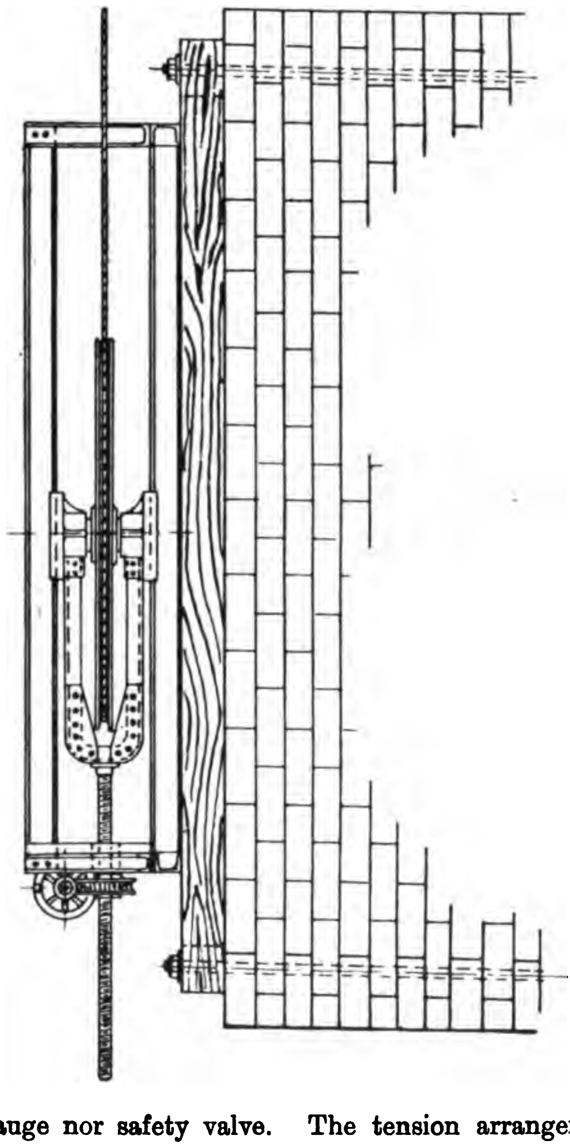


FIG. 217.
TIGHTENING ARRANGEMENT FOR ENDLESS-ROPE HAULAGE.

pressure gauge nor safety valve. The tension arrangement, whilst putting sufficient strain upon the rope to keep it properly working, should be free to give and take, to adjust itself to

varying loads and strains. The unyielding arrangement shown in fig. 217 (*see page* 363) is only permissible where a properly constructed and weighted tension carriage is connected with the same rope at some other point. Personally, the writer does not advocate its use at all.

From the plan view, fig. 209 (*see sheet* 6, *between pages* 356 *and* 357), it will be seen this haulage arrangement was put down for an output of 1500 tons in eight hours from two haulage planes, each 2000 yards long.

Figs. 211, 212, and 213 (*see sheets* 6 *and* 7, *between pages* 356 *and* 357) show a somewhat similar arrangement, so far as the engine on the surface is concerned, but the endless driving rope in this case gives motion to a horizontal shaft instead of the vertical arrangement. The plan view of the engine shows the arrangement of the gearing—a pair of engines coupled to one crank shaft, upon which is the flywheel, and a double-helical pinion gearing into the double-helical wheel on the second shaft; this also carries a double-helical pinion, which gears into the spur wheel on the rope-wheel shaft. The engines have cylinders 24 inches diameter by 54-inch stroke; the rope wheel is 10 feet in diameter. The middle wheel on the horizontal shaft underground is also 10 feet in diameter, and the driving rope coils three or four times round it. The course of the rope from the engine can easily be followed by reference to the figures; passing over the deflecting pulley at the top, down the shaft, under the deflecting pulley at the bottom of the shaft, round the tension pulley, which is mounted on a carriage and weighted in the proper way, thence coiling round the rope wheel, and back up the shaft and to the engine.

On either side of the large 10-foot driving pulley is a haulage pulley, each 8 feet in diameter, fitted with brake and friction clutch, so that either rope may be stopped or started without interfering with the other. These two pulleys deal with the two brows—one with an inclination of 1 in 4, the other 1 in 3. The arrangement of deflecting pulleys for the haulage ropes is clearly shown in the illustrations. Both of the haulage arrangements referred to represent what is termed "over-rope" haulage—that is, the ropes are carried over the tubs.

Fig. 214 (*see pages* 358 *and* 359) shows an arrangement of

cross-compound hauling engine erected on the surface, working the haulage ropes directly; that is to say, there is no strap or driving rope transmitting the motion to a vertical or horizontal shaft underground, but the haulage ropes themselves are driven by the haulage engine. It will be seen that the arrangement of gearing on the engine is the same as before, except that the rope-wheel shaft carries two rope wheels, one on each side of the spur wheel, with a friction clutch for throwing them in or

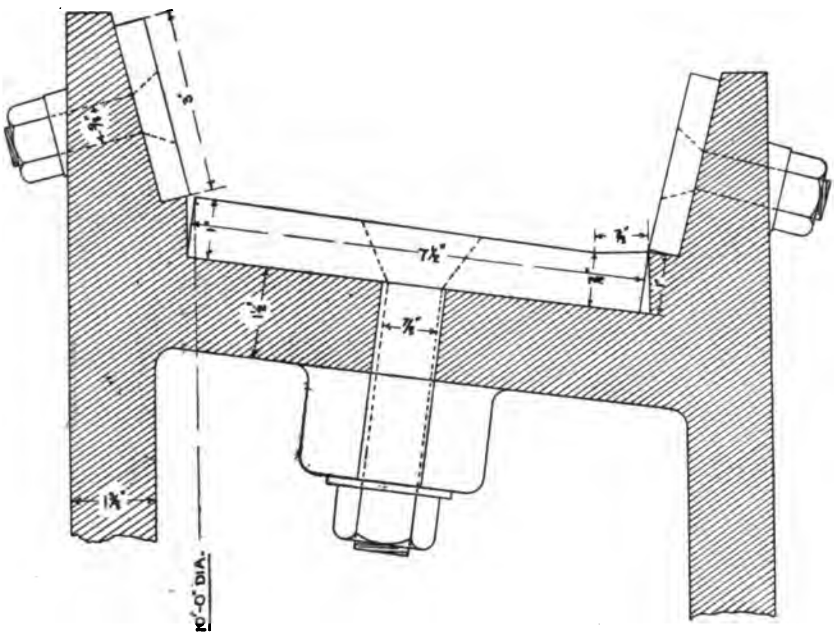


FIG. 218.

SHOWING A SECTION OF THE RIM OF A TAPER TREAD HAULAGE PULLEY, 10 FEET DIAMETER, WITH RENEWABLE TREAD AND CHEEKS. MESSRS. J. WOOD & SONS LIMITED, WIGAN.

out of gear. Here, again, the intention is that the engine shall run more or less continuously, the haulage ropes being stopped and started as desired by means of the friction clutches.

The rope pulleys were formerly plain C pulleys; that is, the rim was semi-circular in section, and the necessary frictional grip between the pulley and the rope was obtained by coiling the rope a sufficient number of times round the pulley. It was found, however, in course of time, that the wear of the rim was not uniform, or, rather, that it was uniform in a peculiar manner, inasmuch as the wear was greater at the side where

the rope coiled off than where it coiled on to the pulley. As a result of this experience, the usual practice now is to provide the rope wheels for endless-rope haulage—the driving wheels that is, either those which are meant to give motion to a rope or those which are driven by a rope for the purpose of working branches—with a taper tread. (*See fig.* 218, *page* 365.) The surface upon which the rope works is thus a small section of a large cone; the rope coils on at the larger diameter, coils spiral-like round the wheel, and leaves it at the smaller diameter. It will be noticed that in nearly all the illustrations in connection with endless-rope haulage where pulleys are shown they are of this type. See, for example, figs. 208 and 210 (*sheet* 6, *between pages* 356 *and* 357), and fig. 215 (*sheet* 8, *between pages* 360 *and* 361). When the inclination is properly adjusted to the rope and the load the action is quite smooth, and free from slipping and jerkiness, whilst the life of the rope is increased as compared with its work upon the older form of pulley. Care must be taken, however, to see that the rope coils on at the larger diameter and off at the smaller. The writer recently heard of a ropemaker advocating the reverse operation. Take Punch's advice and "don't." Suppose we take a pulley 8 feet diameter at the smaller diameter, and 8 feet 3 inches at the larger, and suppose, further, that the rope coils on at the smaller diameter first; the length of the first coil will be 25·132 feet long, the last coil will be 25·918 feet—that is to say, there is an increase of nearly 9½ inches in the length of that coil of rope in working its spiral course round the pulley from the smaller to the larger diameter. Of course, no actual elongation to this extent does take place, but the strain tending to produce that elongation is constantly exerted; the rope is gradually stretched and weakened, and, at the same time, there is a considerable amount of slipping on the pulley, which means extra wear on the rope. Or to put it in another way; suppose the pulley to make 10 revolutions per minute, that is, the rope coils on at the rate of 251 feet per minute, and coils off at the rate of 259 feet per minute, or 8 feet per minute faster than it goes on. This actually is clearly an impossible thing for the rope to do; but, as we have put it before, the tendency is there, the strains are set up, there is excessive slipping and grinding, and both the rope and pulley suffer in consequence.

A little consideration, or, better still, a little practical experi-

menting, will quickly convince one that, even on a cylinder, a rope coiling on and making two or three turns before coiling off again, the last coils are much tighter than the first. This is further demonstrated by the experience with the C pulleys already referred to. In the taper pulley, with the rope coiling on the larger diameter first, we anticipate this condition of things; we make the path of the rope easier and smoother; we neutralise to some extent that tendency to tighten up in successive coils, still retaining sufficient frictional grip to enable the rope to drive the pulley, or the pulley to drive the rope, as the case may be.

Taper pulleys are, or ought to be, provided with a loose renewable tread, and also renewable cheeks. As these parts become worn, they are easily replaced at very much less cost, less inconvenience, than entirely new pulleys. (*See fig.* 218, *page* 365.)

Other forms of rope pulleys have been advocated, with a view to providing a sufficient grip, but these have not met with a large amount of encouragement; they nearly all have a more or less injurious effect upon the rope.

FRICTION CLUTCHES.

For putting different ropes in and out of motion a friction-clutch is a most desirable arrangement. The various ropes can then be smoothly and gradually set in motion without stopping the haulage engine or otherwise interfering with the other ropes. At the same time, the friction clutch becomes a sort of safety valve, safeguarding the haulage rope to some extent in the case of excessive overload.

In starting up one of the ropes shown in figs. 208 and 209 (*see sheet* 6, *between pages* 356 *and* 357), for instance, the vertical shafts carrying the haulage pulleys are both in motion continuously, receiving power, as they do, from the same driving rope. The handle operating the friction clutch is slowly turned until the friction becomes sufficient to impart motion to the rope pulley. At first the motion is less than that of the driving pulley, because the clutch slips a little until the operation of the handle has tightened it up sufficiently. It will now be seen that if the clutch is carefully adjusted, so as to grip properly on ordinary loads, if from any cause there is a heavy overload the clutch will slip and save the rope from excessive strain. (*See figs.* 215 *and* 215A, *on sheet* 8, *between pages* 360 *and* 361.)

As previously remarked, true endless-rope haulage requires a double road; the rope travels continuously in one direction, and the tubs should be attached at equal intervals, the full ones on one side and the empties on the other, either singly or in sets of two or three. In mines where it is not possible, or very difficult, to keep wide roads to accommodate a double line of rails, a modification is adopted by which a single road is used for the greater portion of the haulage plane, with passing places at suitable intervals, and the tubs are attached to the rope in gangs. Such an arrangement, although it answers well enough, does not give the same advantages as true endless-rope.

The difficulty of keeping open wide roads has in some instances been overcome by setting apart separate and distinct roadways for the full and empty rope. This also answers well enough, but it increases the cost, in consequence of having to increase, sometimes to double, the number of haulage hands and attendants.

Endless-rope haulage may be considered as over-rope and under-rope, according to the position of the haulage rope relatively to the tubs. In the former the rope is above the tubs, in the latter underneath. Both systems have their advantages, and those who have been familiar with one system only will probably express the opinion that that particular system is the better. The writer is more or less familiar with both, and must confess to a leaning towards the under-rope system.

In over-rope haulage the tubs must not be filled above the top of the tub; if any coal does project above the top it will most certainly be swept off by the rope in course of transit. With the under-rope this objection is absent.

When the rope is on the top of the tub, and there is any tendency to pull to one side, the rope has considerable leverage to overturn the tub or pull it off the rails. With the rope under the tubs, between the rails, there is little or no leverage, and the tendency is to keep the tubs on the rails.

Where corners have to be negotiated with the ropes over the tubs, the curve, as a rule, has to be rather sharp, and two large pulleys have to be erected in strong framework to carry the rope round the corner. With the under-rope the curve may be made with as large a radius as desired, thus reducing

the liability of derailment of the tubs, and reducing the friction caused by the grinding of the wheels as they pass round the curve. In place of the large pulleys the rope is guided round the curve, still keeping its position between the rails by means of the cone pulleys attached to the successive sleepers in the curved portion of the road, or by means of the pulleys shown in fig. 219, which are also intended to be secured to the sleepers. Furthermore, the two elevated ropes are somewhat of an obstruction in the roadway, the ropes on the floor are not. On the other hand, it is contended that there is more

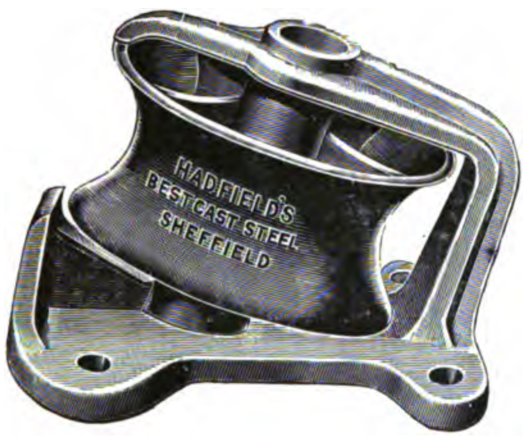


FIG. 219.
HAULAGE PULLEY FOR CURVE ON ENDLESS-ROPE HAULAGE PLANE.

friction and wear and tear on the rope under the tubs, whilst the rope carried on the top of the tubs escapes this friction. To some extent this is true, but with a properly carried out system of under-rope haulage, with friction rollers at regular and suitable intervals (*see fig.* 191, *page* 338), the amount of friction and wear and tear is reduced to a minimum.

Where there happens to be a hump in the haulage road, caused by a change of gradient, the over-rope exerts a considerable crushing strain on the tubs, and the writer has seen tubs broken in this way; the under-rope passes over suitable pulleys let into the floor in such a case, and this effect upon the tubs is absent. On the other hand, where the change of gradient produces a hollow, there may be a tendency for the under-rope to lift the tubs off the rails, a fault which is not so apparent in over-rope haulage. The remedy is to tail out any

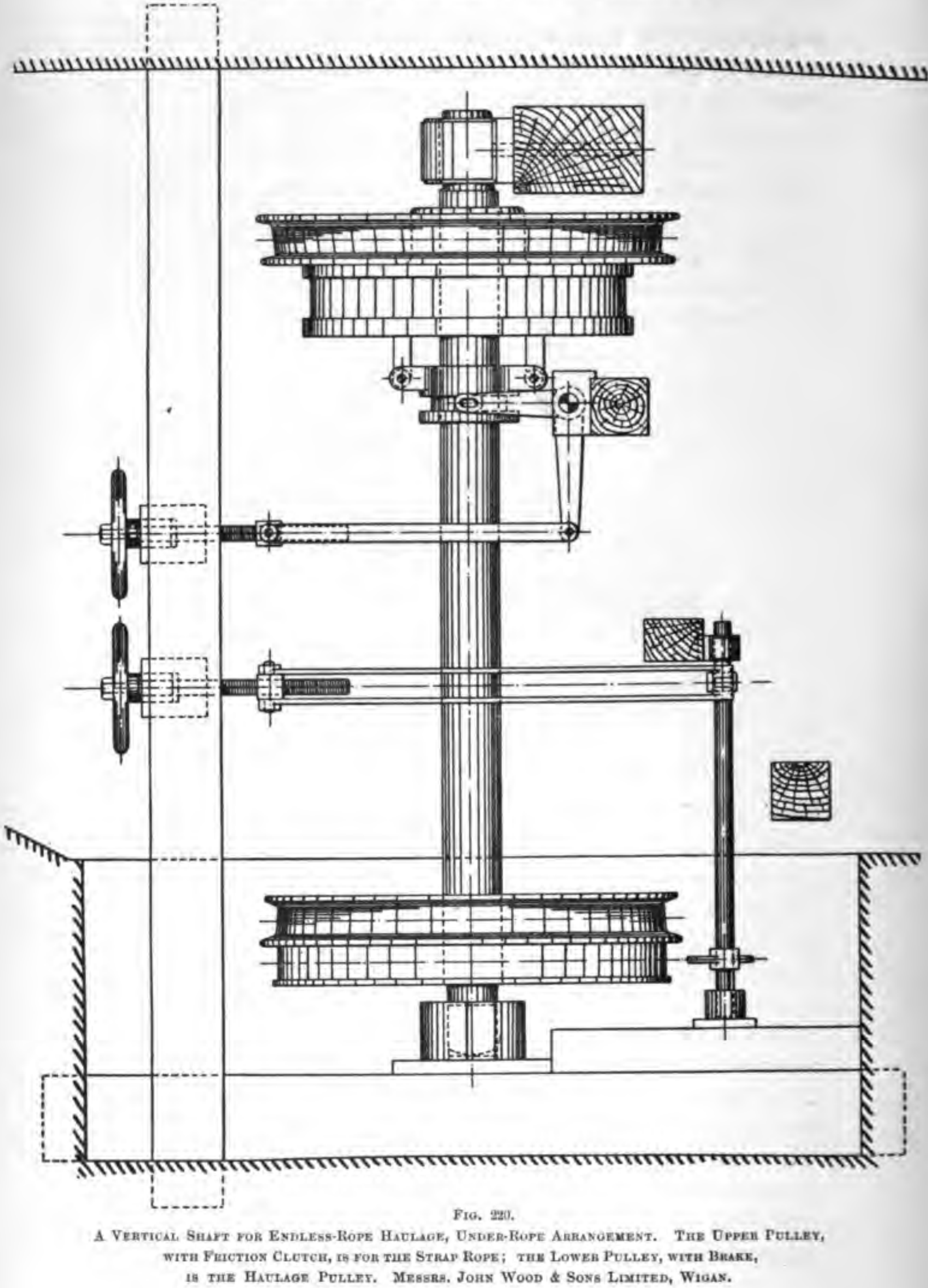


FIG. 220.
A VERTICAL SHAFT FOR ENDLESS-ROPE HAULAGE, UNDER-ROPE ARRANGEMENT. THE UPPER PULLEY, WITH FRICTION CLUTCH, IS FOR THE STRAP ROPE; THE LOWER PULLEY, WITH BRAKE, IS THE HAULAGE PULLEY. MESSRS. JOHN WOOD & SONS LIMITED, WIGAN.

changes of gradient, to spread the change over as long a distance as may be necessary to effect the change—in other words, gradually.

Fig. 220 shows the arrangement of vertical shaft for under-rope haulage where the power is transmitted by endless rope. The power rope drives the upper pulley, which in this instance is loose on the shaft, to which it is connected by a friction clutch; the lower pulley, with the brake ring, is the haulage-rope pulley. Usually the haulage pulleys are loose and provided with friction clutches, so that if necessary two ropes may be worked from the one shaft, and either one stopped or started without interfering with the other one.

ATTACHMENT OF TUBS TO THE ROPE.

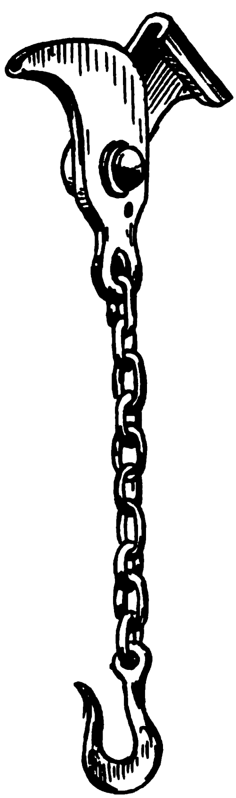


FIG. 221.
HAULAGE CLIP FOR OVER-ROPE HAULAGE, USED IN STEEP GRADIENTS AT BRADFORD COLLIERY, MANCHESTER.

Numerous methods of attaching the tubs to the haulage ropes are possible; with the over-rope system the simplest arrangement is the "lashing" chain. This is a short length of chain terminating in a hook at either end; one end is attached to the drawbar of the tub, and the other is given two or three turns round the rope and then hooked back upon itself. This arrangement is found to answer perfectly for moderate inclinations, and where the gradient is of an undulating nature this attachment is made fore and aft, to prevent the tub over-running the forward chain where the gradient changes.

Fig. 221 illustrates a useful type of clip for over-rope for fairly steep inclinations; the writer is acquainted with these clips in use in mines as steep as 1 in 3. The chain is attached to the drawbar of the tub, and the clip hooked on to the rope; the cam-shaped jaw closes on to the rope and grips it securely. As will be seen from the construction of the clip, the greater the load the firmer will be the grip upon the rope. These hold the tubs quite

Fig. 222.

Hadfield's Haulage Clips for Endless Rope.

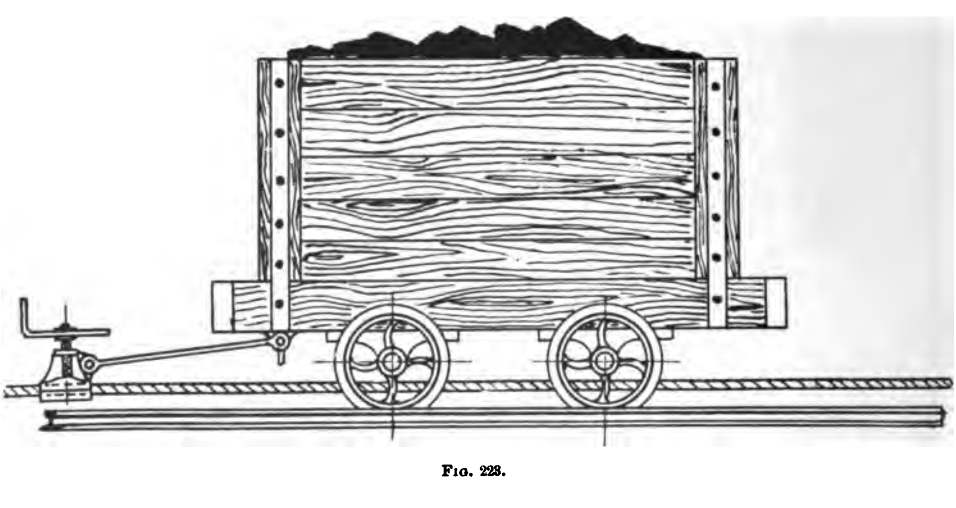


Fig. 223.

securely in the steep brows, indeed they cannot be detached whilst the load is on the chain. On the other hand, when the tubs are hauled up to the level it is a simple matter

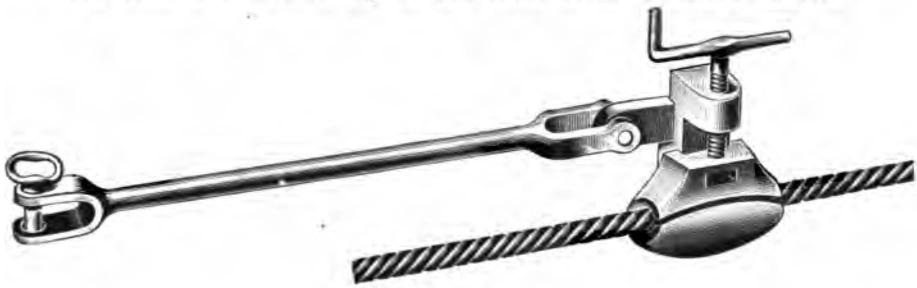


FIG. 224.
A SCREW-CLAMP TYPE OF HAULAGE CLIP.

to disconnect and remove the clip; they will pass round the guide pulleys in the haulage roads without difficulty, and altogether represent an excellent arrangement.

FIG. 225.
CROSS SECTION OF SMALLMAN'S CLIP.

For under-rope haulage clips of some kind are a necessity, and numerous ideas are in operation. For comparatively flat mines the arrangements are simple enough, but where the gradients are steep something of a more substantial character is wanted.

For convenience these may be divided into positive grip clips, like Smallman's well-known haulage clip, and the screw type shown in figs. 222, 223, and 224, and the cam arrangement, like the one already illustrated (*see fig.* 221, *page* 371), of which a further example is given in fig. 231 (*see page* 378), which are self-adjusting, and take a firmer hold on the rope as the pull increases.

The Smallman clip is too well known to require more than a brief description here; the later patterns are illustrated in figs. 225 (*see page* 373), 226, and 227. The two steel plates or cheeks are made to grip the rope between the two shaped portions at the bottom, by the operation of the lever, the short end of which moves in the curved incline planes or recesses formed in the steel plates.

Fig. 226.—Smallman's Clip.

Fig. 297.—Smallman's Clip.

It is made in seven sizes, for ropes varying in diameter from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches. A conspicuous feature about this clip is, that not only can the desired grip of the rope be ensured by adjusting the bolt (*figs.* 228 *and* 229), but wear of the various

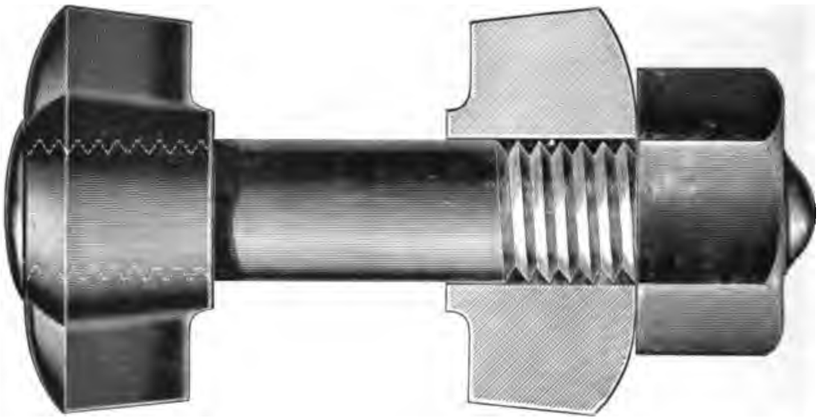


FIG. 228.
ADJUSTING BOLT FOR SMALLMAN'S CLIP.

working parts of the clip itself can in the same way be fully compensated for. Hook and link couplings, which are attached to the shells of the clip by a cotter-pin, are supplied

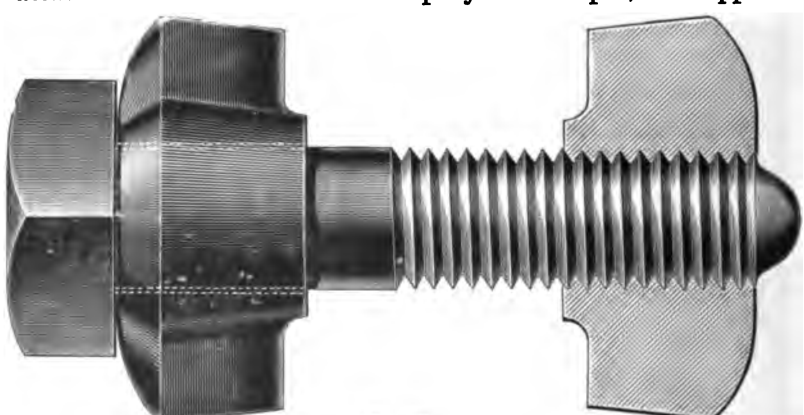


FIG. 229.
ADJUSTING BOLT FOR SMALLMAN'S CLIP.

in great variety, to suit different conditions. This clip is at work on very steep gradients, and goes round severe curves with the utmost ease. We understand, however, that it is necessary for the curve rollers to be carefully laid out and securely fixed,

and for the tension of the rope to be properly regulated. To show the ease with which this clip can be handled, it is only necessary to remark that at one colliery, where the gradient is unusually steep, the hooker-on thinks little of making 1400 attachments and 1400 detachments in each day of 8½ hours. At many collieries it is considered superfluous to lock the lever, but a most excellent automatic locking catch is supplied when thought desirable. The jaws of the clip vary in length from 4¼ inches in the smallest size to 6 inches in the largest, and, therefore, do not injure the rope in the slightest degree. This clip is used for railway wagons on inclines at sidings, as well as for the ordinary colliery tubs.

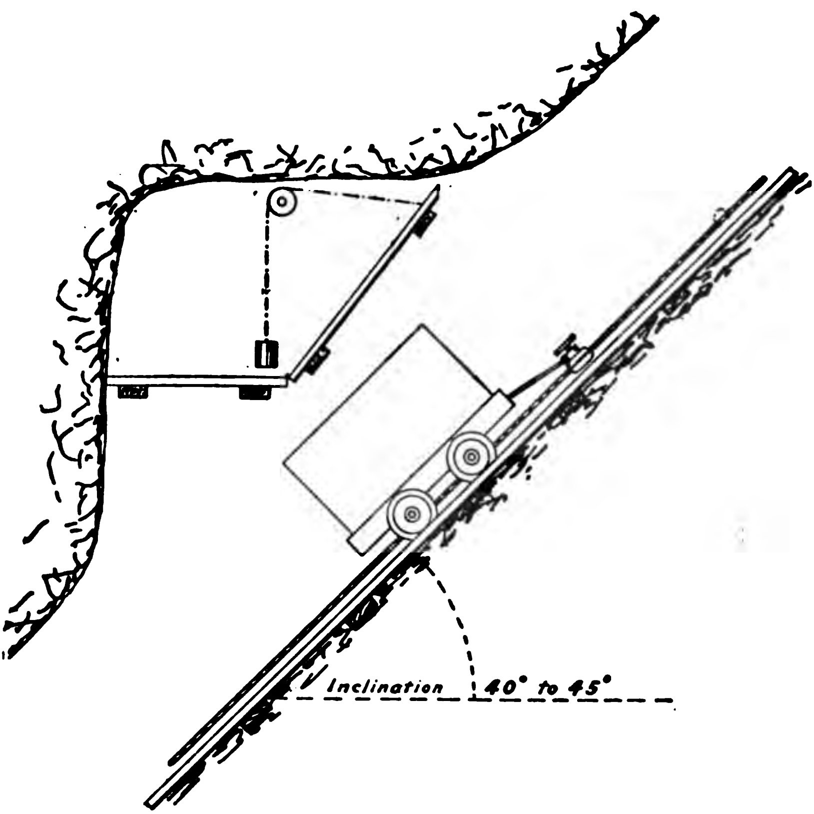


FIG. 280.
SHOWING THE USE OF SCREW-DOWN CLIPS IN ENDLESS-ROPE HAULAGE (UNDER-ROPE) IN A STEEP MINE.

At a Lancashire colliery with which the writer is connected endless-rope haulage is applied in mines having the very steep inclination of from 40 to 45 degrees from the horizontal. The clips used here are of the screw-clamp type of specially strong construction. The clamp is operated by means of a screw and wheel, and the jaws, which are slightly curved so as to get a firmer grip of the rope, are made of steel. A rigid drawbar or rod, terminating in a ram's horn hook, serves to connect the clip with the drawbar of the tub. (*See fig.* 230, *page* 377.)

The rope travels slowly, $1\frac{1}{2}$ to 2 miles per hour, and the clips are put on and taken off whilst the rope is in motion. Although these clips are very strong the writer is not quite sure that they are quite perfect. The difficulty is this: Take the case of a tub just attached to the rope at the bottom of the brow; the clip is screwed down as tightly as possible, but as the tub ascends the brow, and others are added below, the rope must stretch somewhat. The natural elasticity of the wire will admit of this stretching, as the strain upon a given spot in the rope works up to a maximum. As the rope stretches its diameter is slightly reduced—of course it will be understood we are not suggesting a permanent stretch, merely the temporary

FIG. 231.
WAIN'S CAM CLIP.

stretching due to the elasticity of the rope—and this reduction in diameter may effect the security of the clip on the rope. Mr. E. B. Wain has devised a powerful clip of the cam type, which is working with perfect results in the steep mines of the

Chatterley Whitfield Collieries in North Staffordshire. Mr. Wain's clip is illustrated in fig. 231, an inspection of which will make its construction and application clear. The clip is

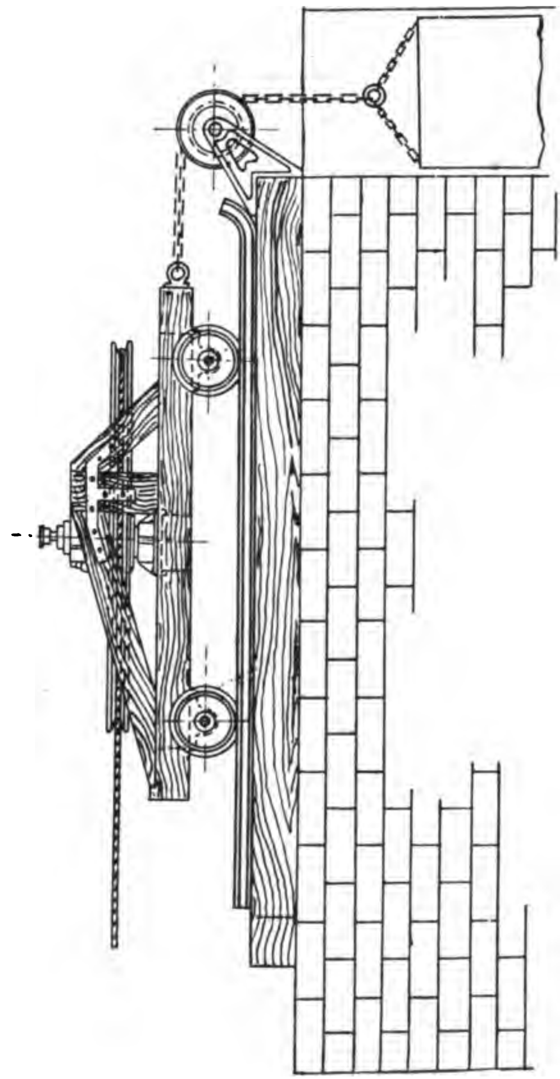


FIG. 232. TENSION CARRIAGE FOR ENDLESS-ROPE HAULAGE. MESSRS. J. & E. WRIGHT LIMITED.

attached to the tub by means of the long drawbar with the ram's horn hook; the rope is gripped by the action of the cam, and it will be seen that this type of clip is not affected by the

stretching or elasticity of the rope—the grip on the rope depends upon the pull of the load, and the greater this is the more securely does the clip hold the rope.

Mention has already been made to the provision necessary in endless-rope haulage for taking up slack rope and maintaining the proper degree of tightness. The best type of tension arrangement is the one in which a pulley is mounted in a frame or carriage, fitted with four small wheels running on rails. A chain attached to the back end of the carriage, passing over a suitable pulley, is weighted sufficiently to keep a suitable degree of tension on the haulage rope. By this

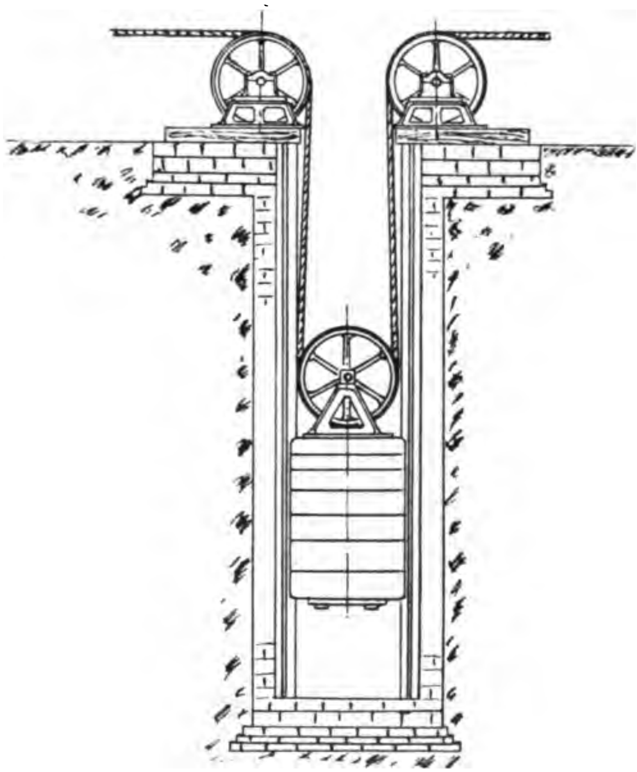


FIG. 288.
TIGHTENING ARRANGEMENT FOR ENDLESS-ROPE HAULAGE.
MESSRS. J. & E. WRIGHT LIMITED.

method the strain upon the rope is not likely to be seriously exceeded; the carriage advances and retreats as the strain on the rope momentarily varies. Examples of such arrangements

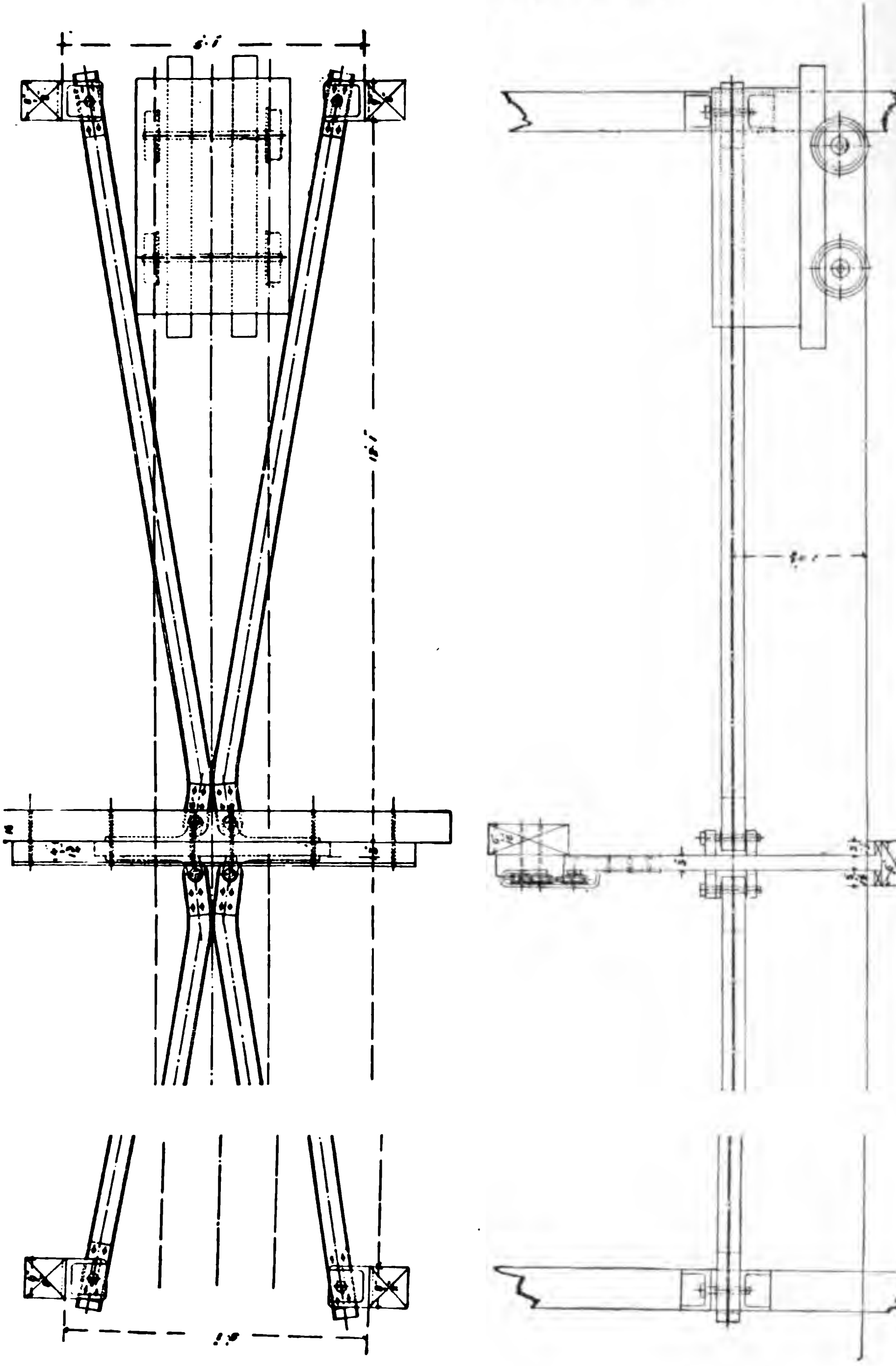


FIG. 234.—PLAN AND ELEVATION OF AN AUTOMATIC DOOR ON AN ENDLESS-ROPE HAULAGE ROAD. MESSRS. JOHN WOOD & SONS LIMITED, WIGAN.

are illustrated on sheets 6 and 7 (*between pages* 356 *and* 357), and further in fig. 232 (*see page* 379). Fig. 233 (*see page* 380 shows another idea which has little to recommend it; the bending backward and forward of the rope, in so short a distance, over pulleys which of necessity cannot be made as large as they should be, very rapidly brings about the destruction of the rope. The tension arrangement shown in fig. 217 (*see page* 363), although frequently used, possesses not a single redeeming feature, and is illustrated in these pages as an example of something to be most carefully avoided. It is an appliance which enables a great and unknown strain to be put upon the ropes, and is absolutely unyielding in its character.

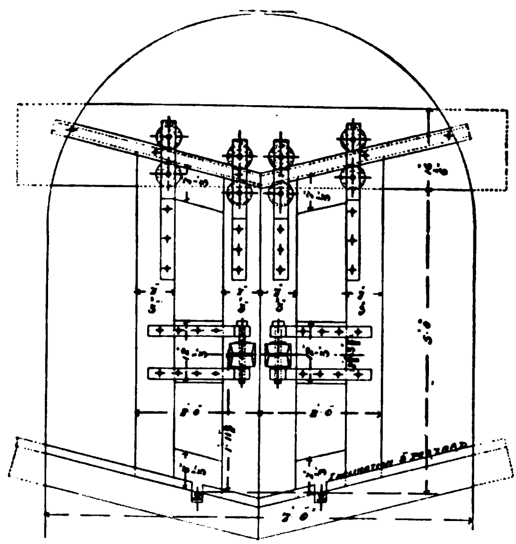


FIG. 234A.—END ELEVATION OF FIG. 234.

Fig. 234 illustrates an arrangement intended to be used in conjunction with endless-rope haulage planes in which it is necessary, in connection with the ventilation of the mine, to provide air doors. The door is arranged to be opened gradually by the approaching tub, and as gradually closed after the tub has passed through. The drawing explains itself. Each door is in two halves, which slide apart instead of opening on hinges, the rollers carrying the doors run on rails to which an upward inclination is given, so that the tendency is always for the door to close.

On either side of the roadway, and about twelve feet away from the door, before and behind, a pair of light steel girders are arranged, as shown, with their ends attached to the doors in such a manner as to form long acute angles, or V's. In approaching the door the tub pushes these aside, thus opening the door, and after passing through the girders on the other side allow the doors to close slowly as the tubs pass away.

HAULING ENGINES.

Where steam or compressed air supplies the motive power for haulage the engines should consist either of a pair coupled, or, in the case of steam, the compound engine may be adopted, the cross compound being the most convenient arrangement—that is, the high-pressure engine on one side and the low-pressure on the other. As a rule, condensing engines cannot well be employed underground, but the surface endless-rope haulage engines at most modern collieries, where steam power is applied for this purpose, are both compound and condensing.

Powerful brakes must be applied to the drums of direct and main-and-tail haulage engines, and to the rope wheels of endless-rope engines for hauling in steep mines. A quick-action throttle valve, and reversing gear also, form necessary features in the equipment of the hauling engines, as well as the hand wheels for operating the clutch gear. Examples have been given showing how to calculate the size of hauling engines. Some further examples, as well as a number of useful notes, will be found at the end of this chapter.

ELECTRICITY FOR HAULAGE.

Latterly electrical energy has been largely introduced for colliery haulage, and there can be little doubt that for underground haulage, and the transmission of the necessary power, it offers advantages which place it at least on an equal footing, if not before, the best systems formerly possible. The transmission of power by means of long, endless driving ropes, although convenient, becomes very costly when the distances and the loads to be dealt with are considerable. Electricity possesses the virtue of convenience in a much higher degree, and becomes more economical. The subject has been sufficiently

dealt with elsewhere; it is only necessary here to add a few remarks with regard to electrical haulage gears.

The speed of rotation of an electric motor is very high, as compared with the revolutions of a haulage wheel or drum, and consequently reduction gear must be employed in the construction of an electrical haulage engine.

The first point to be considered is the manner in which the motor transmits its motion to the heavier gearing. We may adopt a belt or rope drive, or we may employ direct gearing. A good deal of diversity of opinion exists as to which is the better course to adopt, the direct train of gearing or the flexible belt or rope drive. The latter absolutely protects the motor from vibration or jar in working, but it calls for considerably more space in the excavation of the underground engine room, and adds to the cost. On the other hand, some very large motors have been successfully applied directly geared to the haulage engine, and the practice is gaining in favour. It seems to be very largely a matter of excellence of construction. If the motor shaft is provided with a machine-cut pinion—raw hide pinions are giving excellent results—and if the spur wheel into which this pinion gears also has machine-cut teeth, smooth and silent running can be ensured. For the heavier gears, on the second and third-motion shafts, the gearing should consist of wheels and pinions with double-helical machine-moulded teeth. An electrical haulage engine constructed on these lines will be more compact, self-contained, and quite as smooth running an appliance as the externally-driven machine in which the motor drives through a belt or through grooved pulleys and cotton ropes. In all electrical haulage gears, except very small slow-speed machines, we strongly advocate the application of a friction clutch in the train of gearing. The provision of the clutch adds a little to the first cost, and we often find that it is either omitted altogether, or that a simple claw clutch is provided. The latter is almost useless. Our contention will be made clear by a consideration of the following: Suppose we have an electrical haulage gear in which the motor revolves at 500 revolutions per minute, and the rope pulley for endless-rope haulage makes eight revolutions per minute. In the course of working an accident happens in the haulage plane, which calls for the immediate stoppage of the rope; a

signal is given and if a friction clutch is provided, the rope wheel is immediately thrown out of gear and the rope stopped. On the other hand, in the absence of a friction clutch the electric switch is opened and possibly a brake is applied; but the rope wheel, although only moving slowly, forms portion of a train of gearing on which one important part, the rotating element of the motor with its pinion, is revolving at 500 revolutions per minute, and this cannot be brought to rest, without injury, as quickly as the slowly-revolving rope wheel could in the

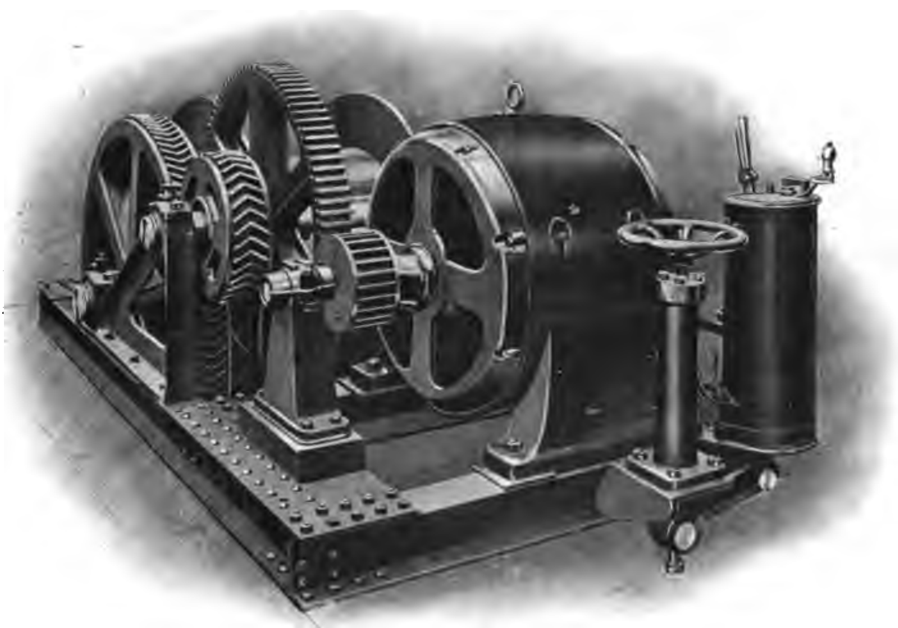


FIG. 235.
A SINGLE-DRUM HAULAGE GEAR, WITH A BRITISH THOMPSON-HOUSTON 60 H.P. CONTINUOUS-CURRENT MOTOR.

former case. A perceptible space of time must be occupied in slowing down the motor, and although, as one engineer with whom the writer was discussing the point urged, "it would only mean a few seconds," a good deal of damage can be done in a few seconds, possibly attended with loss of life. The friction clutch obviates all this, and, moreover, it adds greatly to the

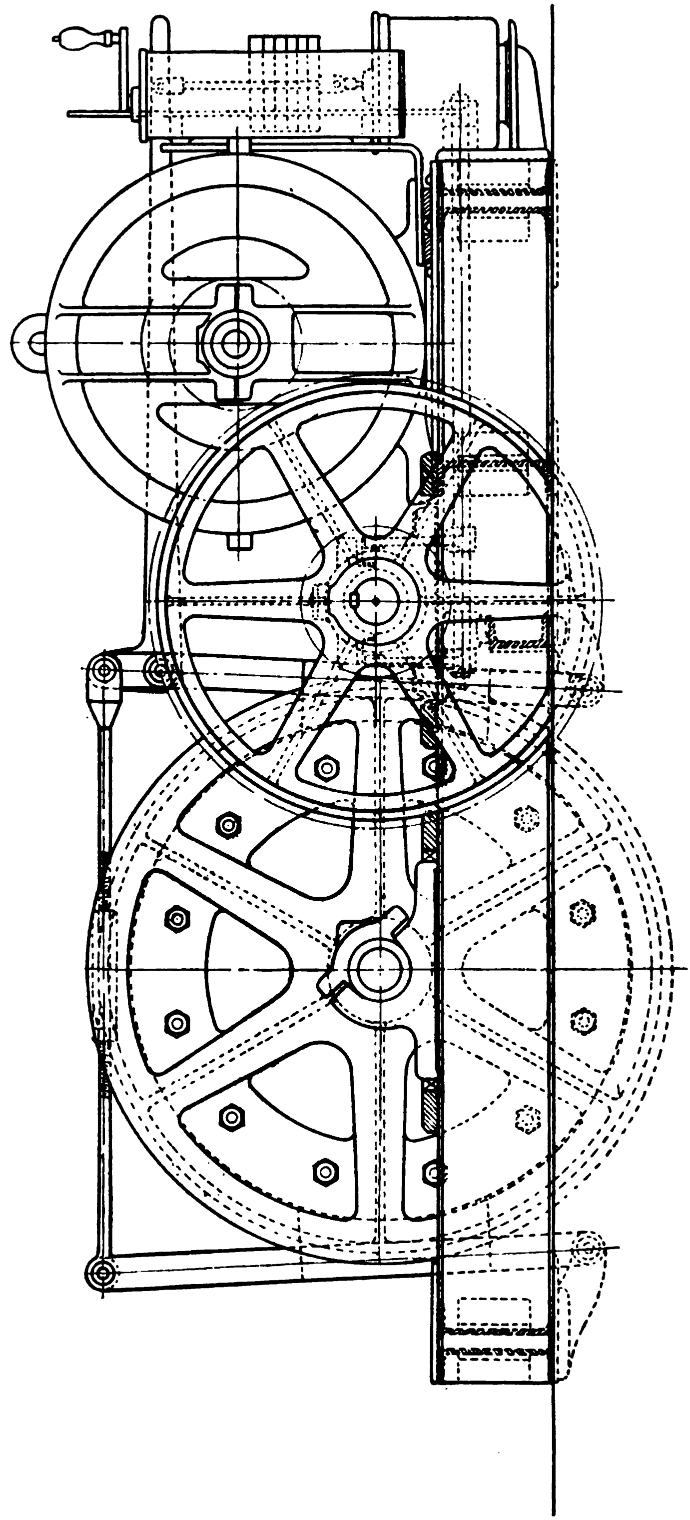


Fig. 296.

Elevation of a Single-Drum Electric Hauler. Messrs. Mather & Platt Limited.

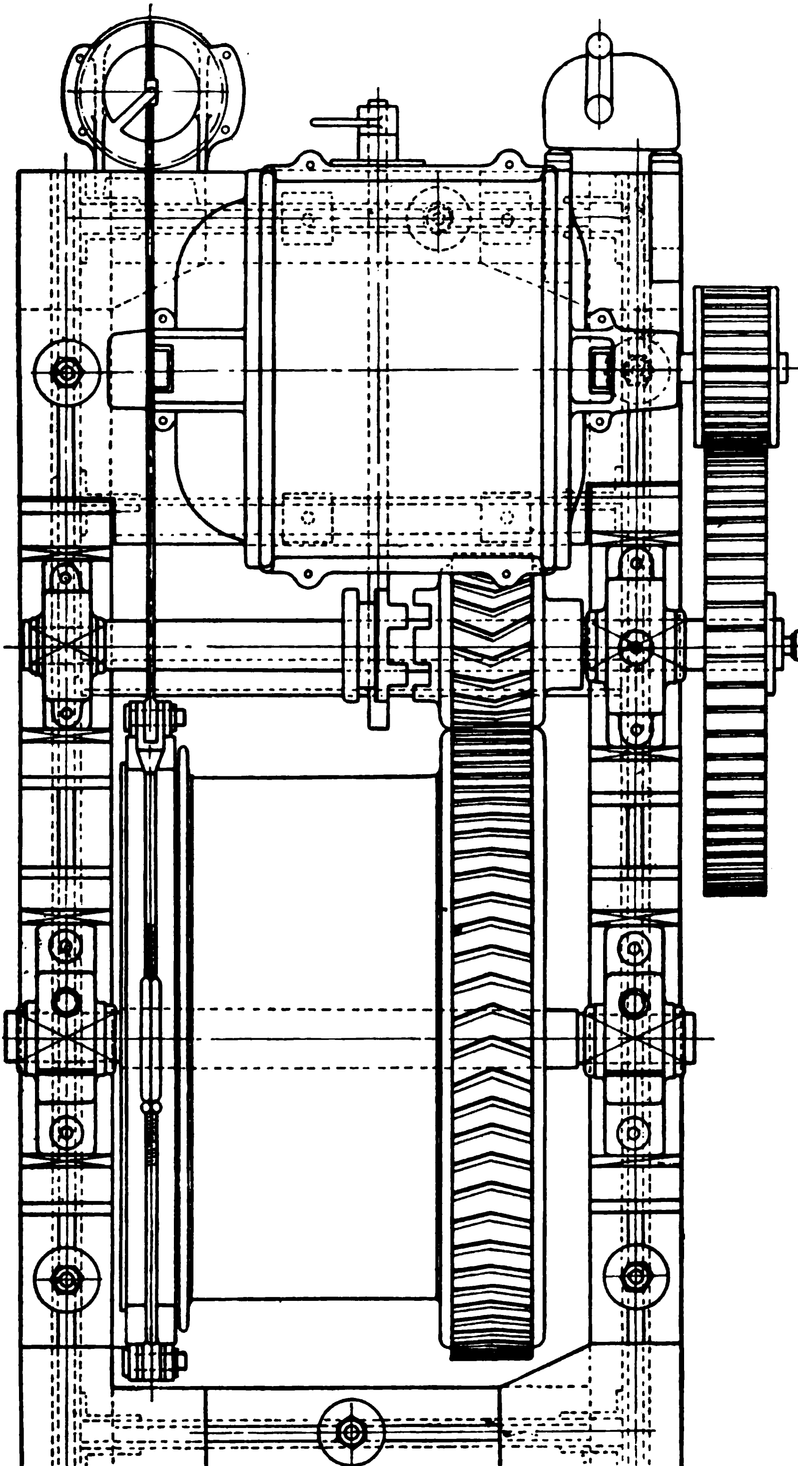
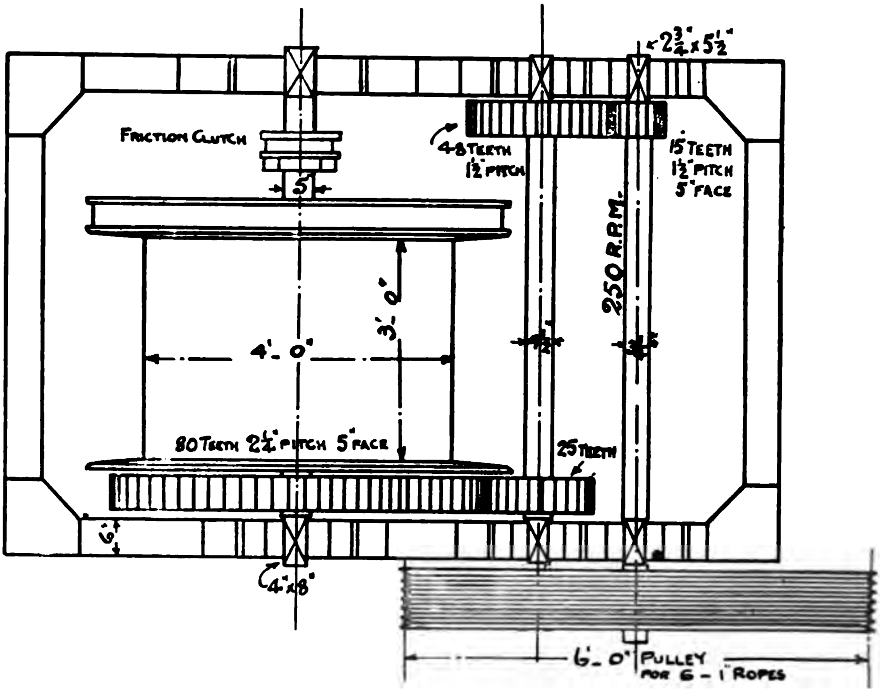


Fig. 237.—Plan of Single-Drum Electric Hauler. Messrs. Mather & Platt Limited.

convenience of the haulage gear and its manipulation. We entirely fail to see why the arrangement is objected to at all, the very slight additional cost is the only possible and a very poor objection.

The electrical haulage gear is controlled, in addition to the mechanical contrivances for operating the clutch and brake, by

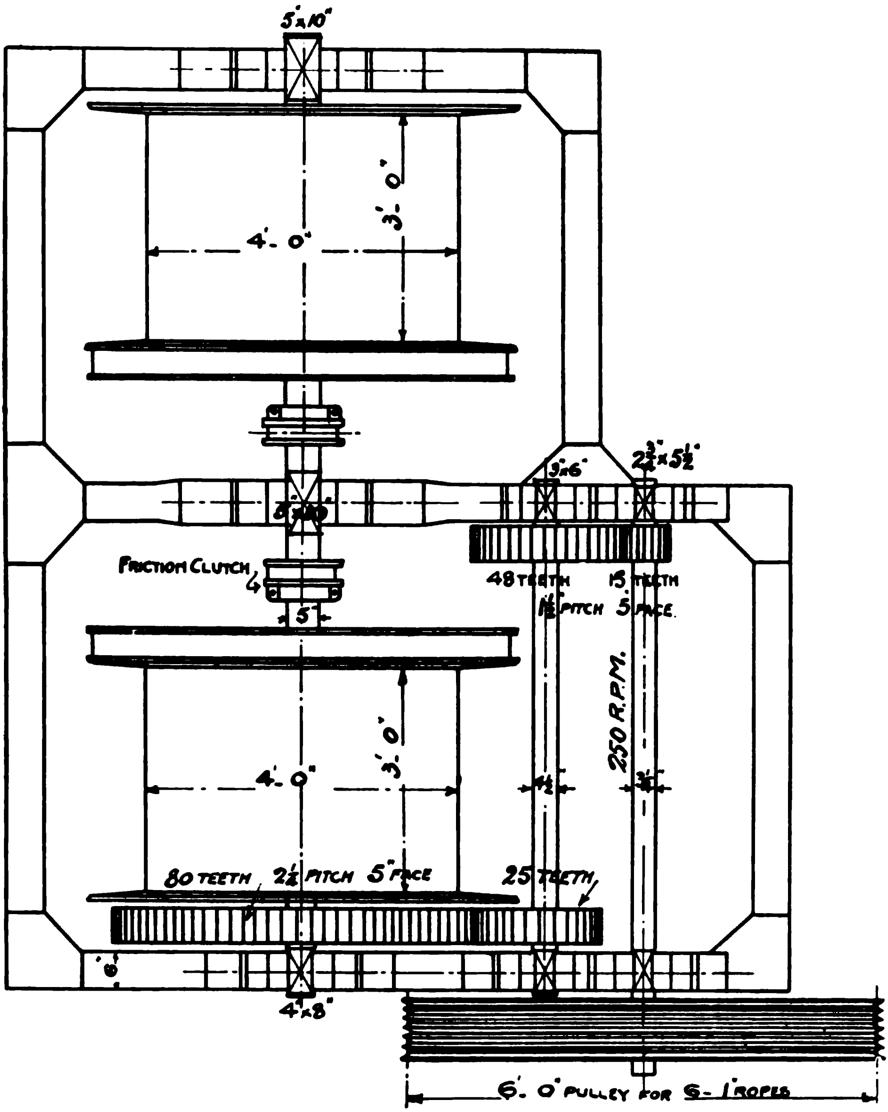


ELECTRIC HAULAGE GEAR WITH SINGLE DRUM.

FIG. 238.

means of a switch and a motor starter or controller, by which the motor may be started gradually, its speed controlled within certain limits, or, if necessary, its direction of motion reversed.

Fig. 235 (*see page* 385) is a good example of a self-contained direct haulage set made by the British Thompson-Houston Company Limited. It is mounted on a built-up steel girder underframe, the motor is a continuous-current 500-volt machine, compound wound, of 60-horse power. The pinion on the motor shaft is of raw hide, gearing into a machine-cut spur wheel; the remaining gears are half-shrouded double-helical wheel and



ARRANGEMENT OF ELECTRIC HAULAGE GEAR WITH DOUBLE DRUM.

FIG. 239.

pinion. The drum gives a rope speed of about four miles per hour; the motor is controlled by a tramway-type controller.

Figs. 236 and 237 (*see pages* 386 *and* 387) show respectively a plan and elevation of a somewhat similar arrangement by Messrs. Mather & Platt Limited. A powerful pillar brake is applied to the drum, which is driven by means of double-helical gearing. A claw clutch is provided on the second shaft, and the motor gears directly into the spur wheel on this shaft with the usual raw hide pinion. A tramway-type controller is also applied to this arrangement, the whole forming a compact self-contained arrangement.

Fig. 238 (*see page* 388) is a sketch in plan of a single-drum hauler, mounted on steel girder underframe, with a grooved pulley for external drive from the motor. Fig. 239 (*see page* 389) is a similar arrangement, with two drums and friction clutches.

It may be useful here to give an example showing how to arrive at the speed of the rope in this haulage gear. Reference to the sketch (fig. 238) will show that the first shaft makes 250 revolutions per minute, and the pinion on this shaft has fifteen teeth. The wheel into which the pinion gears has forty-eight teeth, and the pinion on the second shaft has twenty-five teeth, gearing into the wheel on the third shaft, which has eighty teeth. How many revolutions per minute will the drum make, and what will be the speed of the rope?

This is a simple calculation: Multiply together the revolutions per minute of the first shaft and the number of teeth in the two pinions, and divide by the product of the teeth in the wheels, the result is the number of revolutions per minute of the drum shaft: $\frac{250 \times 15 \times 25}{48 \times 80}$ equals 24·4 revolutions per minute.

The drum is 4 feet in diameter, or 12·566 feet circumference, and 12·566 × 24·4 gives 306·6 feet per minute, or rather less than 3½ miles per hour.

Another example, the reverse way, may be of value. At what speed will the motor have to run to give a rope speed of about ten miles per hour with a drum about 6 feet diameter, say 20 feet in circumference? The gears are as follow: The pinion on the motor shaft has twenty-four teeth, and gears into a wheel with eighty teeth, and the pinion on the intermediate

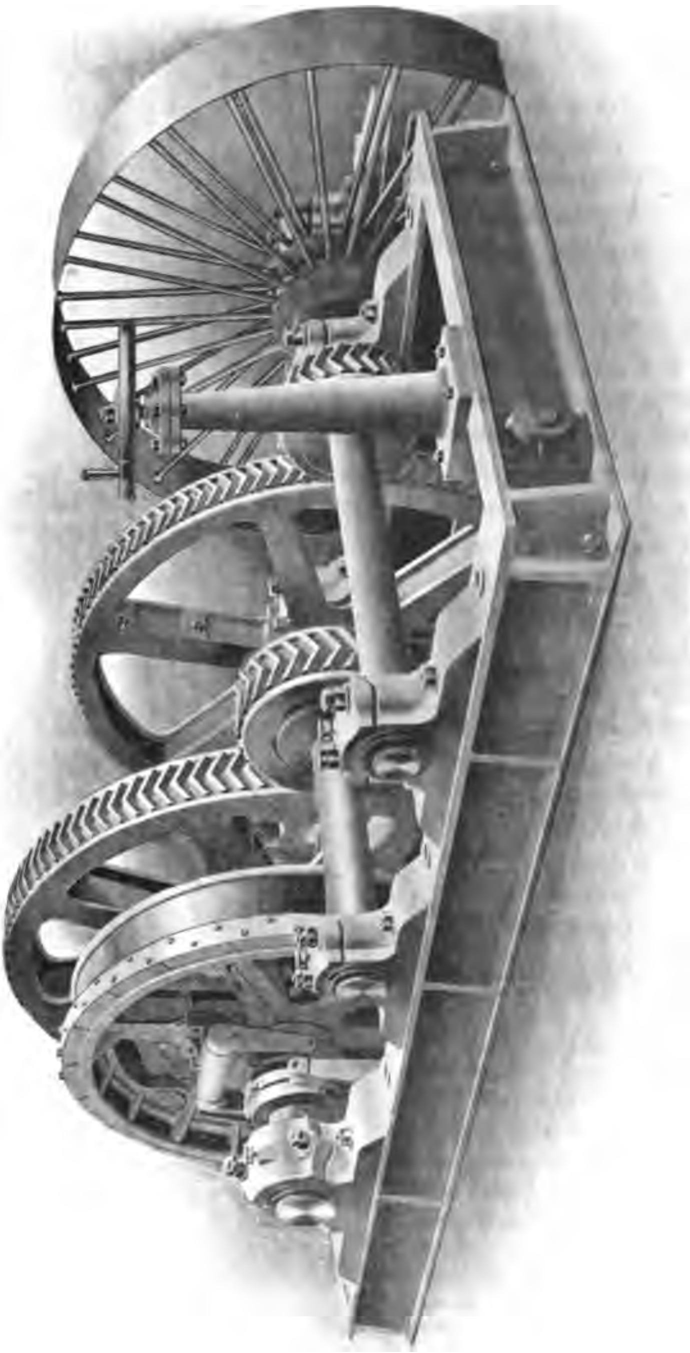


Fig. 240.
Belt-Driven Electric Haulage Gear for Endless Rope. Messrs. Ernest Scott & Mountain Limited, Newcastle-on-Tyne.

shaft has thirty, gearing into a spur wheel on the drum shaft with ninety teeth.

Ten miles per hour equals 880 feet per minute, and 880 divided by 20 gives 44 revolutions of the drum shaft per minute: $\frac{44 \times 80 \times 90}{24 \times 30} = 440$ revolutions per minute of the motor.

Figs. 240, 241, 242, 243, and 244 (*see pages* 391, 393, 394, 396, *and* 397 *respectively*), represent arrangements of endless-rope haulage gears for electrical driving. The photograph (fig. 240) shows a well-designed haulage gear, made by Messrs. Ernest Scott & Mountain Limited. The gear wheels all have machine-moulded double-helical teeth; the rope wheel can be thrown in or out of gear by means of a friction clutch, and the drive from the motor is by means of a belt on to the pulley shown on the right. An almost identical arrangement is shown in the drawings figs. 241 and 242. In this case, however, a grooved pulley is provided for a rope drive from the motor, the grooved pulley being inside the underframe, with two bearings only, instead of the outside pulley shown in fig. 240 with an outside bearing.

There is also a difference in the underframe; in the one case a cast-iron frame is employed, whilst in the other a built-up steel girder frame is adopted. The latter arrangement seems to be rather popular; it is lighter, and probably stronger in proportion to its weight, and has the advantage of being more easily handled in transport underground during erection. The comparatively light steel girders, which can be taken into the mine in small parts, makes the task of transport and erection underground easier, whilst the larger and heavier castings might be difficult to handle. On the other hand, however, we are inclined to think that the latter makes the better job when erected. There is a certain elasticity, or springiness, about the steel girder frame which cannot be altogether good for the smooth working of the gears. A well-designed and carefully-erected cast-iron underframe gives a rigidity and firmness which, in our opinion, is more conducive to smooth and noiseless working of the gear wheels. The arrangement (figs. 241 and 242) would be improved with the addition of a friction clutch on the third-motion shaft, to throw the haulage wheel in and out of gear. A powerful band or strap brake is provided,

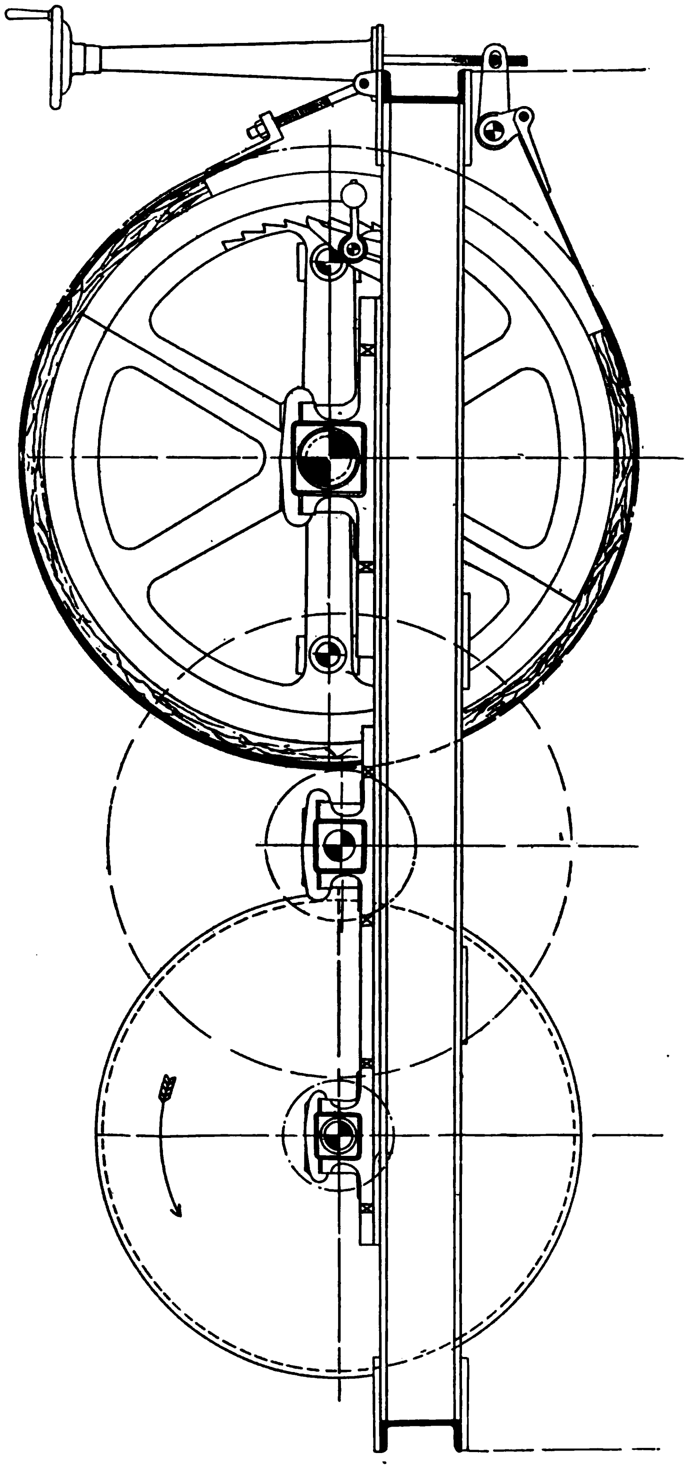


Fig. 241.
Elevation of Rope-Driven Electric Haulage Gear for Endless Rope.

N[2]

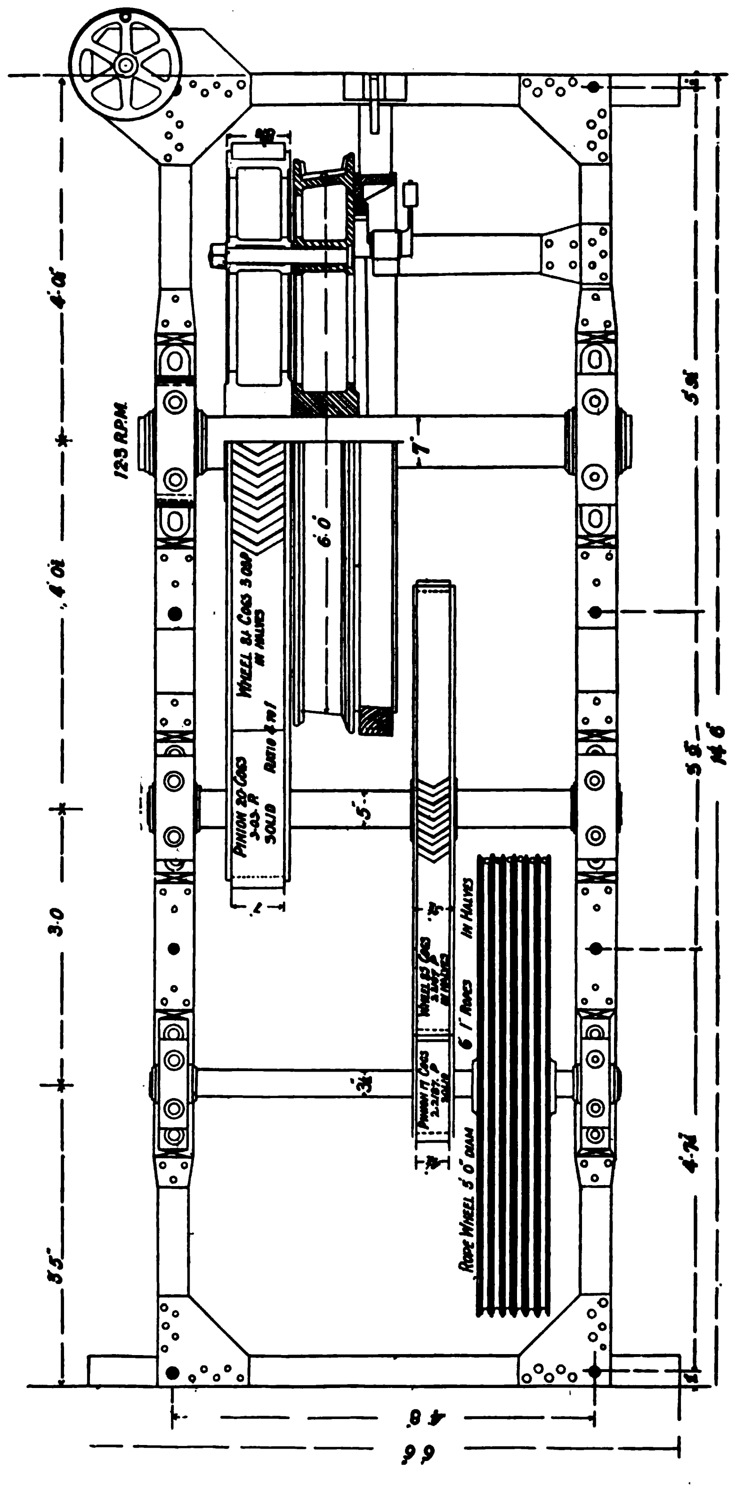


FIG. 242.

PLAN OF ENDLESS-ROPE HAULAGE GEAR, ARRANGED FOR DRIVING BY SIX 1-INCH ROPES FROM ELECTRIC MOTOR. (PLAN OF FIG. 241.)

together with a pawl and ratchet arrangement to prevent reversal, which seems to suggest that the intention is to provide a friction clutch, although not shown in the drawing.

The haulage pulley, 6 feet in diameter, is of the taper tread type, with renewable tread and cheeks, and all the large wheels are cast in halves to facilitate transport in the mine.

The third-motion shaft, according to the drawing, is intended to make 12·3 revolutions per minute, from which we may calculate the speed of the first and second shafts: $\frac{85 \times 81 \times 12{\cdot}3}{17 \times 20} = 249$ revolutions per minute of the first-motion shaft; that is, we multiply the product of the teeth in the wheels by the revolutions per minute of the third-motion shaft, and divide by the product of the teeth in the pinions.

Similarly 81 × 12·3 and divided by 20 gives 49·81, say 50 revolutions per minute of the intermediate shaft; or, working the reverse way, and assuming the speed of the first shaft to be 250 revolutions per minute (which we rather suspect was the intention, the decimal fraction in the revolutions of the third shaft not having been carried far enough), we get: $\frac{250 \quad 17 \times 20}{85 \times 81}$ $= 12{\cdot}34$ revolutions per minute of the third shaft.

The circumference of the rope wheel is 18·84 feet, which, multiplied by 12·34, gives a rope speed of 232·48 feet per minute, or rather over $2\frac{1}{2}$ miles per hour.

Figs. 243 and 244 (*see pages* 396 *and* 397) represent an endless-rope haulage gear in which provision is made on the underframe for the motor, 130 brake horse power, which was intended to be fitted with either a raw hide or machine-cut pinion, gearing into a wheel with machine-cut teeth. The hauling pulley is 10 feet in diameter, and is fitted with a powerful pillar brake.

Elsewhere we have given examples and illustrations of electric motors—three-phase—applied for main-and-tail rope haulage—namely, the installation at the collieries of the United National Company in South Wales, executed by Messrs. Bruce, Peebles & Co. Limited, of Edinburgh. The writer is personally familiar with some of Messrs. Bruce, Peebles' electrical colliery installations, and does not consider it to be out of place—even amongst examples of what are believed to be of the

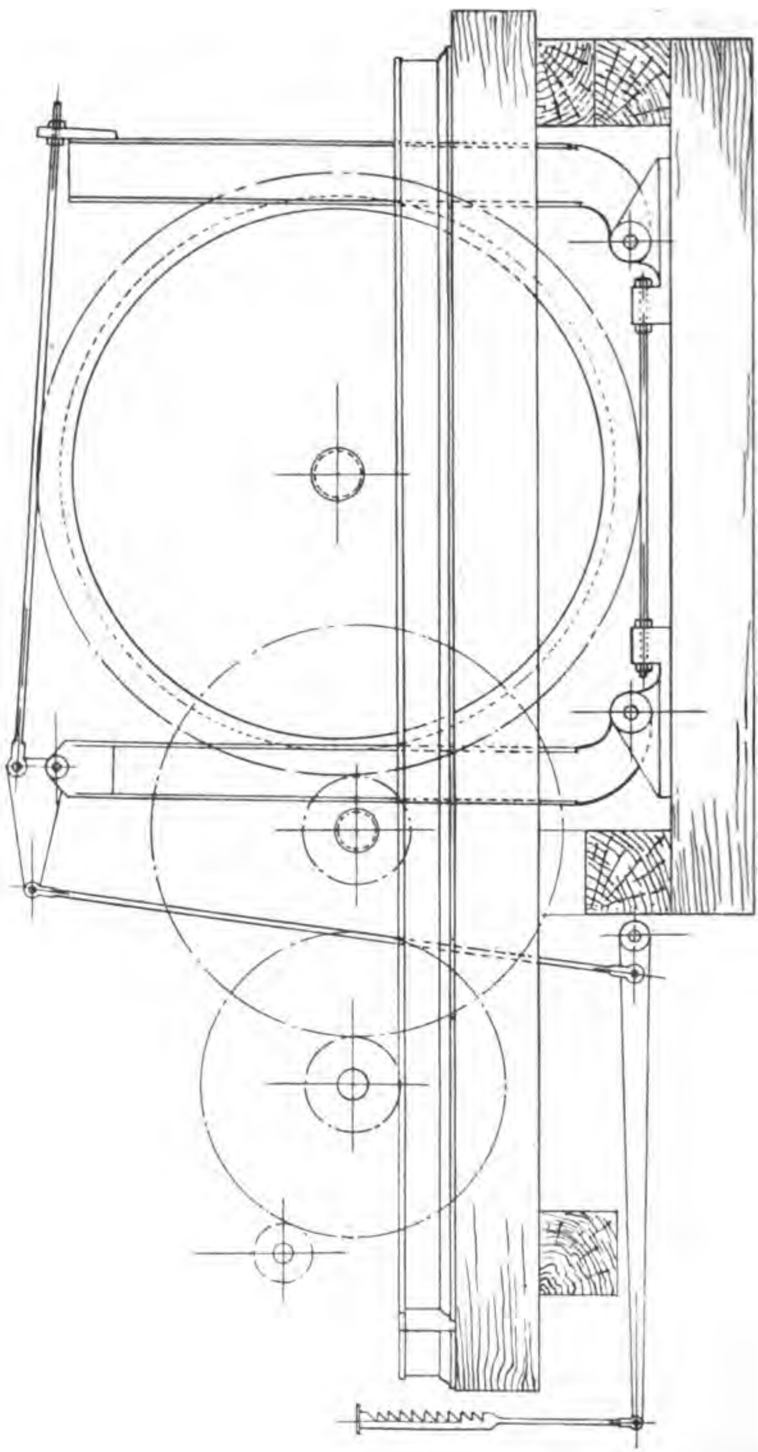


Fig. 248.
Elevation of Electric Haulage Gear for Endless Rope, Direct-Geared to Motor. Messrs. John Wood & Sons Limited, Wigan.

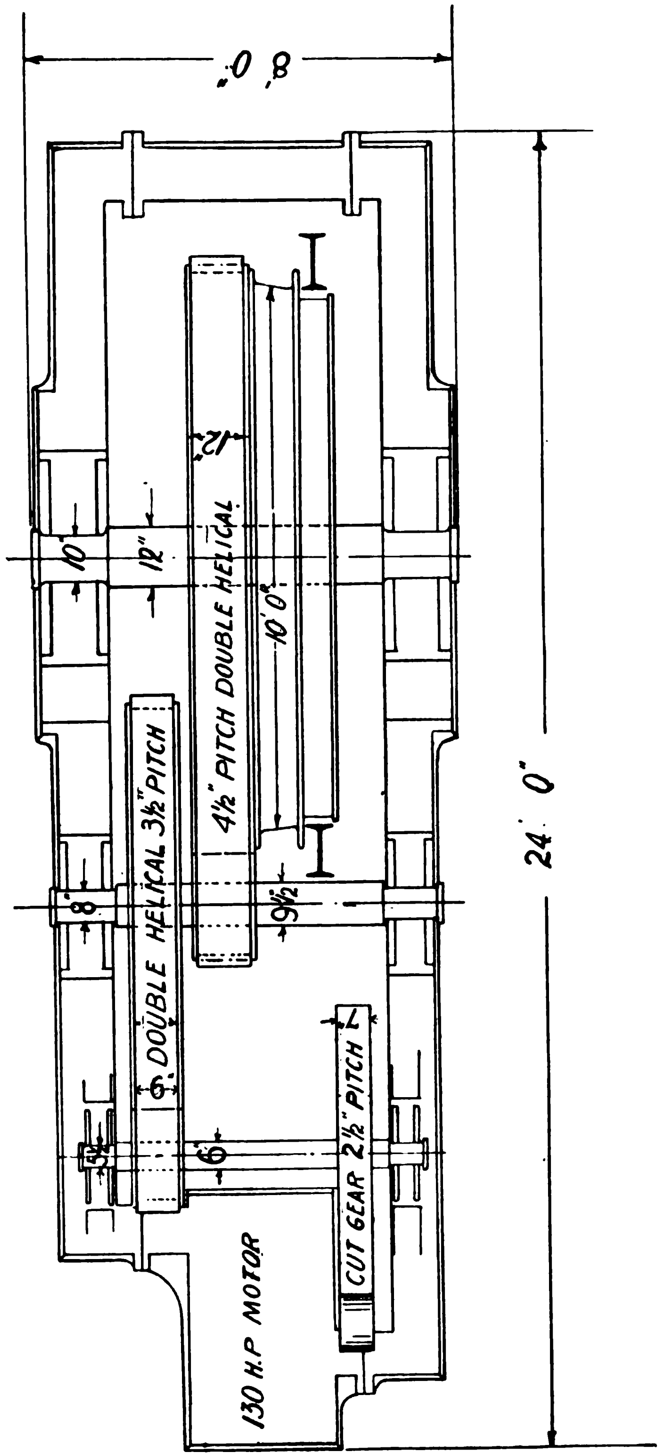


FIG. 244.

ARRANGEMENT OF DIRECT-GEARED ELECTRIC HAULER FOR ENDLESS ROPE. (PLAN VIEW OF FIG. 243.) MESSRS. JOHN WOOD & SONS LIMITED, WIGAN.

best in electrical machinery for collieries—to remark upon the excellence of this firm's work. They seem to have fully recognised what is wanted in a colliery installation, and their installations present a substantial appearance of strength in design which is very pleasing, whilst the test of some years of actual work, under conditions not too favourable, sufficiently demonstrates the character of the workmanship.

The advantages of electrical energy for underground haulage at the present time will scarcely be questioned. A good deal of prejudice has had to be overcome, and, as we have indicated elsewhere, no doubt the imperfect character of many of the earlier applications, together with a want of practical knowledge, and, perhaps, sometimes a certain element of carelessness, and the use of what we have called make-shifts, has had a good deal to do with that prejudice. By this time, however, those who prophesied all sorts of disasters as resulting from the employment of electricity in mines for such purposes have been silenced. With reasonable care, and the proper use of suitable appliances, electricity in a mine is, at least, safer than steam, and there can be no question as to the immense advantage in the cost of electrical haulage plant as compared with steam-driven haulage engines underground, to say nothing of the greater economy in transmission of power, and the lower cost and greater ease of laying electrical cables, as compared with steam or compressed air pipes.

The turning effort of the motor is more uniform and more steady than that of a steam engine, and the motion of the rope is under more perfect control, and works at a more uniformly constant speed. Wherever we turn we find, both in old-established collieries as well as new concerns, that electricity is increasing in popularity for power transmission, especially for underground haulage.

ENDLESS-CHAIN HAULAGE.

It is not intended to devote much space in this work to a system of haulage which scarcely exists outside the Burnley coalfield of East Lancashire—where it has been developed to the fullest possible extent—because, although in the Burnley collieries it is most popular and gives satisfaction, it is not likely to take the place of rope haulage where ropes are already used, nor to be introduced in new haulage arrangements at

collieries beyond the confines of the district where it reigns supreme.

Virtually it is the endless-rope system with endless chains instead of ropes, the details suitably modified.

In the Burnley district, as we have already remarked, the endless-chain system is employed, both on the surface and underground, to the exclusion of almost every other system. It has been applied even to winding, and in the section dealing with that subject a drawing will be found giving details of an endless-chain winding arrangement. To see the endless-chain system of haulage at its best, improved and perfected with the practical experience of half a century or more, one must go to the districts of Accrington and Burnley, in the East Lancashire coalfield.

The chain works above the tubs, and the means of attachment is exceedingly simple. In flat mines all that is necessary is for the chain to rest upon the tub; usually, however, a projection is provided above the end of the tub, with a slot to receive the chain. The tubs are usually made of iron or steel, and should be fairly close together, near enough to prevent the chain dragging on the floor. The speed is, as a rule, slow, from one to three miles per hour, and at curves and landings the attachment and detachment of the tubs is entirely self-acting.

USEFUL RULES AND EXAMPLES IN HAULAGE.

To calculate the strain on a haulage rope due to the effect of gravity in an incline.

The rate of inclination of a brow or inclined haulage plane may be expressed in degrees from the horizontal, or, as is more usual, as an inclination of 1 in so many; 1 in 3, 1 in 5, 1 in 10, and so on. It must be clearly understood that in describing an inclination in this way, the two figures—the 1 and the larger figure—refer respectively to the vertical and the horizontal. Thus 1 in 3 means a rise or fall vertically of 1 foot in every 3 feet, *measured horizontally*.

Now, suppose we have a load of 10 tons attached to the end of a haulage rope, and standing in a brow with an inclination of 1 in 10, the rope alone preventing the load from running down the incline, what is the strain on the rope? For practical

purposes it is sufficiently accurate to divide the load by the horizontal measurement; that is, if the inclination is 1 in 10, divide by 10, which would give a strain on the rope of 1 ton.

To be strictly accurate, however, it would be necessary to calculate the length of the hypothenuse of the right-angled triangle, whose sides, adjacent to the right angle, are 1 and 10, and divide the 10 tons load by this figure.

Thus, adding together the square of $1=1$, and the square of $10=100$, we get 101, and, taking the square root, we get 10·0498, and dividing 10 tons by 10·0498, we get ·99503, which is sufficiently near 1 ton to justify our claiming the first result to be substantially correct. At least the error, small as it is, is on the safe side.

Now, assume the same conditions on an incline of 1 in 5. Dividing 10 tons by 5, we get 2 tons as the strain on the rope. More accurately, we should, as indicated above, multiply by the vertical rise (1) and divide by the hypothenuse—that is, by the corresponding measurement on the incline to a measurement of 5 on the horizontal base.

This length works out to $\sqrt{(1^2+5^2)} = 5{\cdot}099$, and dividing 10 tons by 5·099 we get 1·961 tons, which again is sufficiently near 2 tons to justify our adopting the simpler process for all practical purposes.

Indeed, we might at once say that whilst the correct rule is to multiply the load by the vertical height of the incline, and divide by its length, for all practical purposes for gradients not steeper than 1 in 4, it is sufficiently accurate to divide at once by the latter figure, the figure which expresses the length of the base as a ratio of the vertical height.

From a further example we see at once that in steep inclines, steeper than 1 in 4, the error becomes considerable. Take the same conditions on an incline of 1 in 2. Proceeding to divide by 2 we get $10 \div 2 = 5$ tons as the strain on the rope. Accurately, however, it is less than $4\frac{1}{2}$ tons, thus: $\sqrt{(1^2 + 2^2)} = 2{\cdot}236$, and $10 \div 2{\cdot}236 = 4{\cdot}472$ tons.

TABLE SHOWING GRAVITY OF LOAD DUE TO INCLINE.

(THE ST. HELENS CABLE COMPANY LIMITED.)

Degrees.	Inclination per yard in inches.	One in	Load due to incline per ton in lbs.	Degrees.	Inclination per yard in inches.	One in	Load due to incline per ton in lbs.
1	0·63	57·29	39·08	31	21·62	1·66	1153·68
2	1·26	28·63	78·18	32	22·49	1·60	1187·02
3	1·88	19·08	117·24	33	23·37	1·54	1219·99
4	2·51	14·30	156·26	34	24·28	1·48	1252·58
5	3·15	11·43	195·24	35	25·20	1·42	1284·81
6	3·78	9·51	234·14	36	26·15	1·37	1316·62
7	4·42	8·14	272·98	37	27·12	1·32	1348·05
8	5·06	7·11	311·74	38	28·12	1·28	1379·07
9	5·70	6·31	350·40	39	29·14	1·23	1409·67
10	6·34	5·67	388·97	40	30·21	1·19	1439·84
11	6·99	5·14	427·41	41	31·29	1·15	1469·57
12	7·65	4·70	465·71	42	32·41	1·11	1498·85
13	8·31	4·33	503·88	43	33·56	1·07	1527·68
14	8·97	4·01	541·90	44	34·76	1·03	1556·03
15	9·64	3·73	579·75	45	36·00	1·00	1583·92
16	10·32	3·48	617·43	46	37·27	0·96	1611·32
17	11·00	3·27	654·90	47	38·60	0·93	1638·22
18	11·69	3·07	692·20	48	39·98	0·90	1664·63
19	12·39	2·90	729·27	49	41·41	0·87	1690·55
20	13·10	2·74	766·12	50	42·90	0·84	1715·92
21	13·82	2·60	802·74	51	44·46	0·81	1740·81
22	14·54	2·47	839·12	52	46·07	0·78	1765·14
23	15·27	2·35	875·23	53	47·77	0·75	1788·95
24	16·02	2·24	911·09	54	49·54	0·73	1812·20
25	16·78	2·14	946·66	55	51·41	0·70	1834·89
26	17·56	2·05	981·94	56	53·36	0·67	1857·04
27	18·34	1·96	1016·93	57	55·44	0·65	1878·62
28	19·14	1·88	1051·61	58	57·61	0·62	1899·63
29	19·95	1·80	1085·97	59	59·92	0·60	1920·06
30	20·78	1·73	1120·00	60	62·35	0·58	1939·88

THE LOAD IN HAULAGE.

In direct haulage, single rope, the pull to be overcome by the engine or motor is made up as follows—namely, total weight of coal, tubs, and rope divided by the gradient—that is, for 1 in 5 divide by 5, etc.—plus the friction of the loaded tubs and rope, say one-twenty-eighth, to be on the safe side, of the total weight of the tubs, coal, and rope.

In direct haulage, two ropes, one gang descending whilst the other ascends. Weight of coal and rope in ascending gang divided by the gradient, plus the friction; that is, say, one-twenty-eighth of the total weight of the empty and the loaded gang and one rope.

Main-and-Tail Rope Haulage : Total weight of coal and tubs divided by the steepest gradient, plus one-twenty-eighth of the total weight of tubs, coal, and ropes for friction.

Endless Rope : Maximum weight of coal on rope, divided by

the average gradient, plus one twenty-eighth of the total weight of coal, tubs, and rope.

GRADIENTS IN HAULAGE.

Haulage Levels, or Horse Roads: Gradient to give equal drawing in both directions, from 1 in 80 to 1 in 140 in favour of the loaded tubs, according to the character of the roads, tubs, etc.

Self-acting Inclines: Average about 1 in 18, with no places flatter than 1 in 20.

Direct-acting Haulage Planes: Average 1 in 26 to 1 in 30.

CALCULATION FOR HAULING ENGINES.

Example (taken from one of the examination papers for colliery managers' certificates):—

What is the horse power of a steam engine which is capable of hauling a train of twelve tubs by single direct rope up an incline 600 yards long, inclination 1 in 4, in 4 minutes? The tubs weigh 4 hundredweights, and carry 7 hundredweights of coal. Allowances to be made for the rope and friction.

If a pair of engines, geared 3 to 1, with a drum 5 feet diameter, are employed to do the work, what will be the diameter of the cylinder and the length of stroke, the steam pressure being 60 pounds at the boilers?

Twelve tubs, each $4 + 7$ hundredweights $= 11$ hundredweights $\times 12 = 132$ hundredweights, or 14,784 pounds.

A good quality rope, weighing 3 pounds per yard, has a breaking strength of over 20 tons, which will give an ample factor of safety.

600×3 equals	1,800 pounds.
Add the weight of coal and tubs ...	14,784 pounds.
	16,584 pounds.

Load due to gradient, $16{,}584 \div 4 = 4146$ pounds.

Load due to friction, say, one twenty-eighth $= 16{,}584 \div 28 =$ say, 592 pounds.

Total load against the engine, $4146 + 592 = 4738$ pounds. 1800 feet in 4 minutes = 450 feet per minute, and

$\frac{4738 \times 450}{33,000} = 64{\cdot}6$, say 65 horse power. This is the effective or brake horse power of the engine; the indicated horse power will probably amount to half as much again, or, say, 97 horse power, the difference being accounted for in the engine and gearing friction.

A drum 5 feet diameter $= 15{\cdot}708$ feet circumference, and 450 feet per minute $\div 15{\cdot}708 = 28{\cdot}6$ revolutions per minute of the drum. The engine, we are told, is geared 3 to 1, which means that the crank shaft will revolve $28{\cdot}6 \times 3 = 85{\cdot}8$, say 86 revolutions per minute.

A fair piston speed will be 360 feet per minute: $\frac{360}{86 \times 2} = 2{\cdot}09$, say 2-foot stroke. 97 horse power equals 3,201,000 foot pounds per minute, of which half will be developed in each cylinder, equals 1,600,500.

Take two-thirds of the boiler pressure, equals 40 pounds, as the average effective pressure in the cylinders, and 360 feet per minute piston speed: $360 \times 40 = 14,400$, and $1,600,500 \div 14,400$ equals rather more than 111 square inches as the area of each cylinder —in round numbers 12 inches diameter. The cylinders suited to the drum, gearing, steam pressure, and load given, therefore, would be a pair 12 inches diameter by 2-foot stroke.

We may, with advantage, electrify this example, so to speak, to bring it up to date, and we will calculate further the horse power of a motor to accomplish this duty, and assuming 800 yards between the generator and motor and 525 volts at the generator, we will ascertain the current in amperes and the size of a suitable conductor.

The efficiency of the motor may be taken at 85 per cent, and the gearing about the same, say 70 per cent combined efficiency. Really good gearing would give a higher efficiency, so that we are on the safe side: $\frac{65 \times 100}{70}$ equals, say, 93 electrical horse power of the motor; $93 \times 746 = 69,378$ watts.

It may be assumed that the pressure at the motor terminals will be 500 volts; that is, 25 volts drop between the generator and motor: $69,378 \div 500 = 138{\cdot}75$, say 139 amperes.

The total length of conductor, lead and return $= 800 \times 2 =$ 1600 yards, and by the rule given in the section on "Electricity"

(*page* 217): $\frac{139 \times 1600}{25 \times 40,000} = \cdot 2224$ square inches area of copper in the conductor.

SIZE OF DRUMS AND PULLEYS FOR HAULAGE.

The drums and pulleys used in connection with colliery haulage are only too frequently made much smaller than they ought to be; the result is that the haulage ropes wear out or break quickly, and the cost for haulage is consequently higher than it should be. Drums and pulleys should be made as large as possible; a good rule is to make them not less than 100 times the diameter of the rope. If it is impossible to employ pulleys large enough, the ropes should then be specially ordered, and, instead of the usual rope of six strands of seven wires each, a more flexible rope employed, having a larger number of smaller wires in the strand. Such a rope will not work as long as a six-strand seven-wire rope on pulleys of the proper diameter, but will certainly work longer than six-strand seven-wire ropes on drums or pulleys which are too small.

On this point Messrs. J. & E. Wright, of the Universe Works, Birmingham—to whom we would here express our gratitude, not only for a number of drawings used in this section, but also for a considerable amount of valuable information on wire ropes generally—make the following recommendation:—Take the diameter of the rope in inches, but regard the figure as feet or the fraction of a foot. On this assumption multiply by 6, which gives the minimum diameter in feet for the drum or pulley. For example, take a rope 1 inch diameter: call the 1 inch 1 foot and multiply by 6, which gives 6 feet diameter of pulley or drum for a rope 1 inch diameter. Similarly for a rope $\frac{3}{4}$ inch diameter: $\frac{3}{4}$ of a foot multiplied by 6 equals 4 feet 6 inches diameter of drum or pulley. Messrs. Wright explain that this is the minimum diameter for ropes of good quality; inferior ropes would require larger pulleys.

This recommendation agrees with the experience of Messrs. the St. Helens Cable Company Limited, who advise as to the minimum diameter of drums and pulleys, for good quality ropes of six strands seven wires, seventy-two times the diameter of

the rope, which amounts to exactly the same thing as the rule given by Messrs. Wright.

WEIGHT OF COLLIERY TUBS OR WAGONS.

For the purposes of practical calculations in colliery haulage the weight of the tub or wagon may be taken at one-half of the weight of coal it is intended to carry, except in the case of the large sizes of wagons employed in South Wales, which may be taken at one-third of the weight of coal carried.

Thus a tub to carry 8 hundredweights weighs about 4 hundredweights, one to carry 10 hundredweights weighs 5, whilst the large wagons of 35 hundredweights' capacity weigh about 12.

MILES PER HOUR AND FEET PER MINUTE.

Miles per Hour.	Feet per Minute.	Miles per Hour.	Feet per Minute.
1	88	11	968
$1\frac{1}{2}$	132	12	1056
2	176	13	1144
$2\frac{1}{2}$	220	14	1232
3	264	15	1320
$3\frac{1}{2}$	308	16	1408
4	352	17	1496
5	440	18	1584
6	528	19	1672
7	616	20	1760
8	704	25	2200
9	792	30	2640
10	880	40	3520

Haulage Speeds : Direct rope and main-and-tail rope haulage up to 15 miles per hour; endless-rope and endless-chain $1\frac{1}{2}$ to 3 miles per hour.

HADFIELD'S STEEL CASTINGS FOR COLLIERY PURPOSES.

Having made somewhat liberal use in this section of illustrations of colliery haulage appliances made by Hadfield's Steel Foundry Company Limited, at Sheffield, and having regard to the important part played by steel in modern colliery engineering, it may not be considered out of place, in concluding this chapter, to give a brief account of the large works where so many steel castings for colliery purposes are manufactured.

Sheffield is particularly well worth a visit by anyone intimately connected with the mining industry, for not only is it in itself a coal centre, but one of its famous firms—namely, Hadfield's Steel Foundry Company Limited—may be said to have accomplished more, perhaps, than any other steel firm in the way of supplying colliery requisites. This company is the outcome of a business started as far back as 1872 by the late Robert Hadfield, at the Hecla Works, Attercliffe. At these works, which were comparatively small in extent, being under eight acres, innumerable experiments were carried out in order to determine the best possible grades of steel for different purposes, and as Mr. Hadfield foresaw the uses to which steel has eventually been put in connection with collieries, it is not to be wondered at that a large proportion of the experiments carried out were in relation to steel for mining purposes. Success did not, of course, come straight away, but failures only brought into prominence Mr. Hadfield's conviction that steel was destined to take the place of iron in collieries. By degrees the right material was found, the trade increased by leaps and bounds, and Mr. Hadfield had the satisfaction of seeing his business bidding fair to take its place amongst the great industries of this country. On his death the concern was, in 1888, formed into a limited liability company, at the head of which, as managing director, was installed Mr. Abbott Hadfield, the son of the founder. The ever-increasing business called for more expansion than was possible at the Hecla Works, and subsequently about eighty acres of land, situate at Tinsley, about four miles from the city, were secured for the erection of new premises. The writer has had an opportunity of visiting both these works, and it seems almost incredible that, as he was assured is the case, the land at Tinsley was simply a field in August 1897, yet by March of the following year the works were nearly all built, and the machinery set in motion for manufacturing purposes; this notwithstanding the fact that the ground had to be raised an average of about six feet within that time.

This is an effective British reply to the boasting of American houses anent the rapidity with which big deeds are accomplished on the other side of the Atlantic. We found the old Hecla Works abundantly interesting, being there shown, in

the various stages of manufacture, shells intended for the use of our own and other Governments. Formerly the manufacture carried on at these works consisted of all the different classes of work executed by Messrs. Hadfield, but now the premises are almost restricted to shell production. The new works—the East Hecla Works—cover, as stated, something like eighty acres, of which twenty acres are actually occupied by the different departments. Practically, all kinds of steel castings are made here, comprising both large and small, but still the firm has never lost that close touch with steel requisites for collieries that has been such an outstanding characteristic right from the beginning. We paid a lengthened visit, during which we were shown about every description of article used in mines that could be made at a steel foundry, and yet we left with the impression that, had we stayed longer, there would still have been something further to bring before us. Proceeding, as was only natural, in the first place to the foundry, where the molten metal begins to assume shape, we were very much impressed with the up-to-date type of the building and its equipments. This foundry has a length of over 1000 feet, and occupies about six acres of ground, being, moreover, the largest of its kind in the world. There are in it twenty-two travelling cranes and thirteen jib cranes, with capacities up to twenty tons, whilst the pneumatic system is extensively used, both for sand riddles and other purposes. In one part of the foundry moulds were ready for castings which would certainly not weigh more than a few pounds, and some distance away the finishing touches were just being given to a mould for a cylinder well over twenty tons. We were reluctant to turn away from the heavy work department and the bay devoted to manganese steel. Of ERA manganese steel—one of the firm's specialities—more anon. Personally, we felt we could have lingered indefinitely, there was so much to be learned, but our guide, to whom this great building was, of course, an everyday affair, knew the object of our visit, and seemingly thought that we would wish to go straight to the colliery department; he therefore conducted us to the bay, where tub wheels of sundry sizes were just being cast, also rollers, pulleys, pedestals, pit turns, and crossovers, together with parts for controllers, clips, etc., etc. Vast though the place is, everything has been so systematised that perfect order exists.

Connected with the foundry are three separate buildings which form the annealing shops, and have an area of 50,000 square feet; of annealing furnaces there are thirty-three, some being of very considerable size. The shops are fitted with electric cranes and the appliances needed for the handling of heavy weights. Much of the success attained by Hadfield's castings is undoubtedly due to the thoughtful study which is unremittingly given to the subject of proper treatment. The correct ingredients for good steel are arrived at by chemical analysis, and ordinary precautions ensure the right constituents being used, but it remains for the annealing to give the all-important temper. It is by judicious manipulation during this process that the castings have imparted to them that toughness and durability which are such necessary features, and, further, the strains set up by unequal contraction of the steel when cooling in the mould are removed when the castings are in the furnaces. It will be seen, therefore, that too much attention cannot be given to annealing. Hadfield's fully realise this, and they have consequently made their annealing shops as complete as it is possible. The persistent tapping of hammers indicates the nearness of the fettling-shops, of which there are two, the area being 45,000 square feet. These are likewise fitted with electrical appliances, inclusive of overhead cranes, and it is whilst castings are here that they really take on the form of the finished article, they being thoroughly freed from the sand adhering to them from the mould. Noise of a different character greeted us on our entry into the extensive grinding shop. In this building the ERA manganese steel castings are fettled and ground. Manganese steel is the invention of Mr. R. A. Hadfield, with whose name it is inseparably associated, and the company are the sole manufacturers. Until the discovery of this steel, its unique combination of excessive hardness and extreme roughness was regarded as an absurd conjunction. The advantages of the combination need not be unduly enlarged upon to be recognised, and, it may be said, the only adverse feature the ERA manganese steel possesses is that by reason of its great hardness and tenacity it is commercially unmachinable. This, to a certain extent, limits its use, but wherever it can be cast or forged into the shape desired for meeting particular requirements, its resistance to abnormal

wear and tear, or severe abrasion, is really marvellous. This is why it becomes necessary to grind the roughness off manganese castings, the grinding being done by means of emery wheels.

There are fifteen sets of emery wheels in Hadfield's grinding shop, and as each is provided with a dust extractor, the shop possesses an unusually clear appearance. There were many heaps of manganese general castings about the shop, as well as a good number of wheels being ground, the sparks flying from the emery stone in a veritable pyrotechnic display. Afterwards we visited the machine department, which comprises two large shops, there being ten bays in the two. The buildings have a length of 435 feet, and an area of 124,690 square feet. There are large faceplate lathes, planing machines, and other tools, suitable for dealing with castings of all sizes in the machine department, also nine overhead electric travelling cranes. In this department, of course, the finishing touches are given, and we are told that the major proportion of the castings, more particularly the large ones, are supplied to the purchasers rough machined. It will thus be gathered that not only have the above company laid themselves out for the satisfactory manufacture of steel castings, but they have left nothing undone to ensure the efficient handling and treating of the castings throughout the various processes. To give anything like an exhaustive description of the works would occupy far more pages than are at our disposal, so we will now refer more particularly to the specialities intended for colliery use. For tub axles, rollers, pulleys, pedestals, etc., a special quality of steel is required, as otherwise the action of coal grit would cause the wear to be very great. Hadfield's, therefore, aimed at lightness, durability, and strength—particularly the latter—as being the important properties to be attained. Nowadays steel has made such rapid advances that one is almost inclined to forget that, so comparatively recently, cast iron formed about the only material used for colliery castings. The late Mr. Hadfield determined to bring about a change, and he, and afterwards his firm, have converted intentions into results. To-day the company can make colliery wheels at the rate of 12,000 or more per week, with rollers, pulleys, etc., in due proportion. Hadfield's steel wheels invariably take the place of cast-iron wheels wherever a fair comparative test has been made. Colliery

wheels may be divided into two classes, fast and loose. For wheels fast on axles, with a machine fit, the plan is to bore the wheels, afterwards turn the axles, and then press the wheels on to the axles by hydraulic power, securing by means of a key. The cost of this, however, is rather high, and led to Hadfield's special fast method being devised. For this method the axle is forged in the rough with an octagon taper, merging into a round at the larger end of the octagon. The wheel is cored with a similar shape, and driven on by pressure of several tons. So accurate is the fit that the axle will shear shavings off the inside of the wheel. This plan is both fast and cheap, and is in

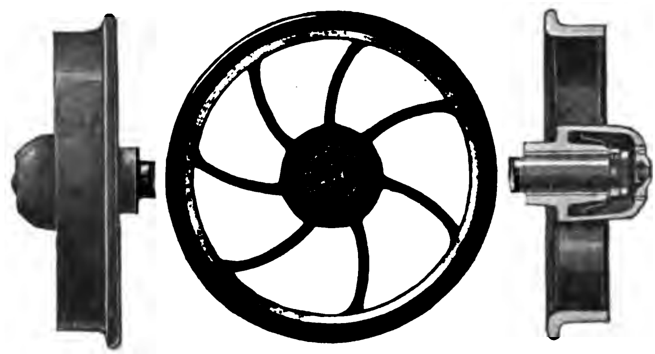


FIG. 245.
ROWBOTHAM'S SELF-LUBRICATING TUB WHEEL.

vogue not only at most of the large collieries in this country but in all parts of the world; it is applied to inside and outside bearings. For those who prefer loose wheels, or whose curves and conditions are such that the fast wheels are not quite suited, an efficient self-lubricating wheel is the desideratum. For such users the Rowbotham type of self-oiling wheel has been designed. Fig. 245 shows clearly the main properties of this wheel. Its merits are economy, light running, absence of dust, absolute freedom from waste through oil leakages, and perfect lubrication. The approximate cost of oiling is but one penny per tram per month. Hadfield's were not slow to recognise the preeminence of the Rowbotham wheel as a self-oiler, and they have now the sole right of manufacture, they working in conjunction with T. Rowbotham & Company Limited, the inventors. It must not be forgotten that fast wheels, too, require lubrication. Hadfield's have not allowed this part to

escape their notice; they supply a thoroughly satisfactory automatic greaser, such as is illustrated in figs. 177 and 178. (*See pages* 322 *and* 323.) The greaser performs its work whilst the corves are running, and is a great advance on former ways, which necessitated a man or boy either getting underneath the tub or turning it over; even then the bearings were very often improperly greased. The tub greaser never fails; it applies only the quantity needed, and is therefore a source of saving; it minimises the power used by the haulage machinery and generally reduces the wear and tear on the haulage mechanism. An admirable pedestal for use in connection with the automatic greaser is the Drury's patent pedestal and guard, of which Hadfield's are the sole makers. We gave a view of the pedestal (*see fig.* 176, *page* 321), which, it will be seen, is as effective as it is simple. The design consists of two grooves, cast along the face of the pedestal to receive a U-shaped strap, which also passes round the axle; the guard secures the axle, and at the same time permits of a complete open bearing.

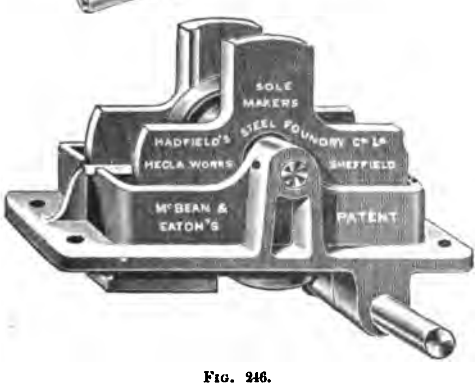


Fig. 246.
McBean & Heaton's Tub Controller.

Mention should be made of another of Hadfield's specialities, known as the McBean and Eaton patent tub controller. This is also illustrated. (*See fig.* 246.) The object of the controller is, as its name implies, to regulate and control the movements of the tubs. It is not, however, a corve stop; it is made to pass either one, two, three,

or four tubs at a time, retaining or releasing one or more, as desired, on a line of rails or upon a cage. Let us suppose a number of detached tubs are held on an incline by this appliance, and it is intended to allow two tubs to pass; the lever is moved either by hand, or, if worked from a distance, by wire or other means, and as the axles of the tubs catch the star projections the barrel of the controller revolves until it has made an entire revolution, when it is prevented from going further by a catch coming up against the shoulders of the barrel, the two arms of which stay the progress of the

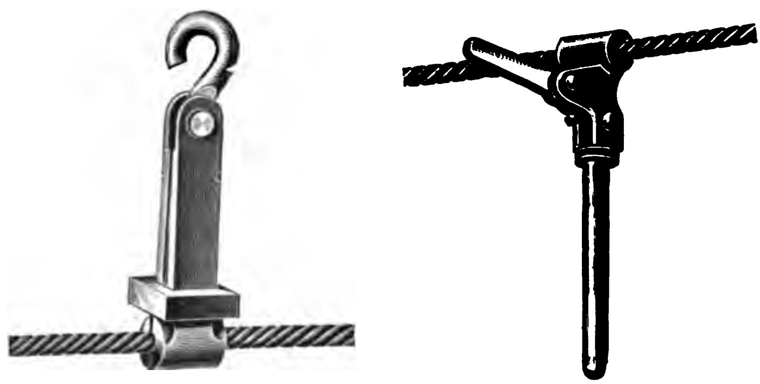


FIG. 247.—HAULAGE CLIPS.

remaining tubs until the lever is again worked. These controllers have stood the test of severe and constant usage, and have been found to be economical, certain in their action, and perfectly automatic.

In connection with rope haulage the local conditions in the different collieries call for varied types of rope clips, and Messrs. Hadfield have catered accordingly. Fig. 247 indicates two designs which have a ready sale, and which should suit the requirements of pretty nearly all mines. (*See also figs.* 222, 224, *and* 231, *pages* 372, 373, *and* 378 *respectively.*)

Now and again, in the newspapers, it is recorded that some poor miner has come to grief whilst engaged in the extraction of props, which, having temporarily served their purpose in holding up the roof, are required to be put in use in another part of the mine. Unfortunately these accidents are not uncommonly attended by fatal results. The old ringer and chain certainly, to some extent, lessened the danger attending

prop-withdrawing, though it by no means entirely removed it. To do this a powerful appliance was wanted, and one, moreover, that could be used whilst the miner himself stood clear of the immediate centre of action. The patented prop-withdrawer supplied by Hadfield's fulfils these conditions; it is shown in fig. 248. The leverage of the machine is thirty to one as against seven to one of the old ringer and chain. It is cheap in working and in the initial price; its uses in the colliery are well-nigh unlimited, as it can be worked, not only for withdrawing props, but for moving weights about in place of a winch. One mineowner found the effective leverage gave such strength to the device that a prop was successfully dragged through five tons of dirt.

FIG. 248.
SILVESTER'S PULLING JACK.

To enlarge their sphere of usefulness in connection with collieries, Hadfield's decided upon the erection of a shop with appliances for making complete tubs. This shop, of which we give a view (*see fig.* 249, *page* 414), is of a thoroughly up-to-date character, efficiently fitted up with all the latest improved machinery for turning out tubs made of either wood, iron, or steel. Hadfield's supply tub bodies only, or the tubs complete, with their own wheels, axles, pedestals, drawbars, links, and hooks. (*See fig.* 250, *page* 415.)

The lack of standardisation which exists in connection with mines renders it incumbent upon steel founders that they should have a most extensive stock of patterns. A glance round the pattern stores at the East Hecla Works makes one feel that no matter what size or style of wheel, roller, pulley, or pedestal, etc., may be called for, Hadfield's will be able to quickly supply the same. They have patterns of wheels of all workable sizes (disc or armed), pedestals of all types (open and

closed), pulleys with **U** grooves, **V** grooves, unequal flanges, wide and narrow grooves, special shaped grooves, chain pulleys,

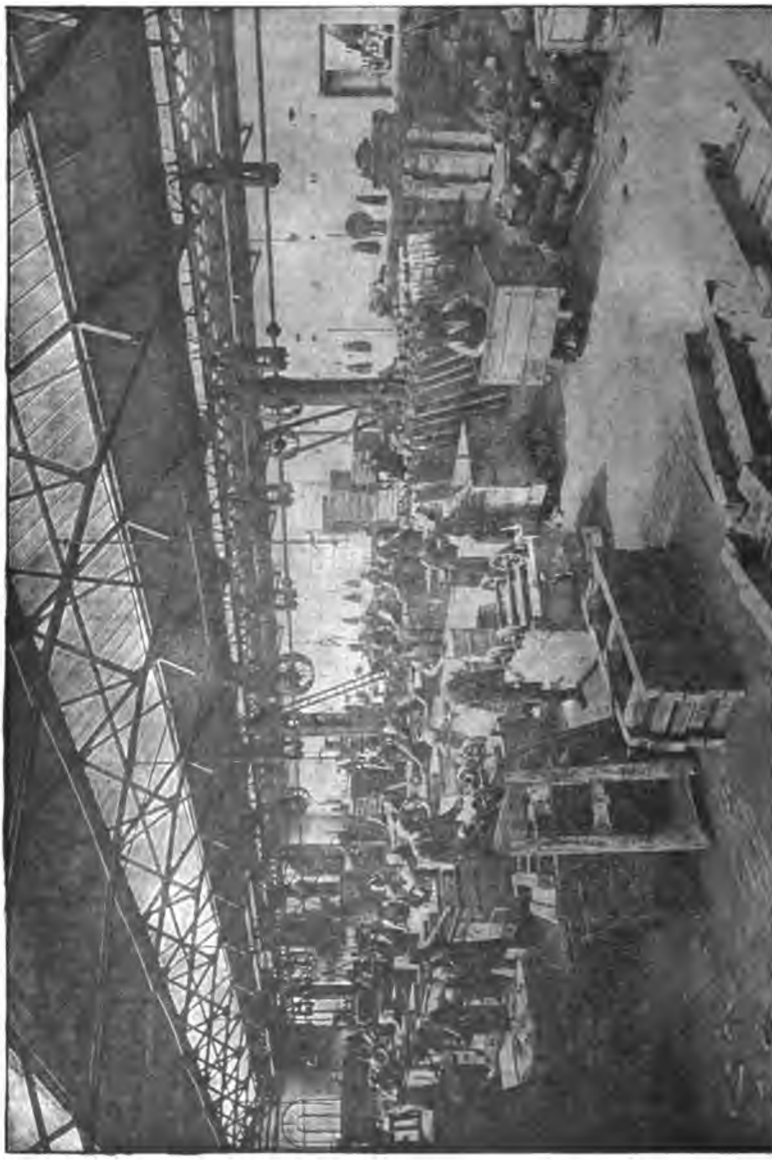


FIG. 249.—HADFIELD'S COLLIERY TUB ERECTING SHOP.

pulleys from 2 inches to 8 feet diameter. Hadfield's also turn out pulleys with renewable liners, with brake rims, and fitted

up on stands or in frames. There are roller patterns (2 inches to 24 inches diameter), rollers of the ordinary parallel design, single flanged, unequal flanges, corrugated, together with

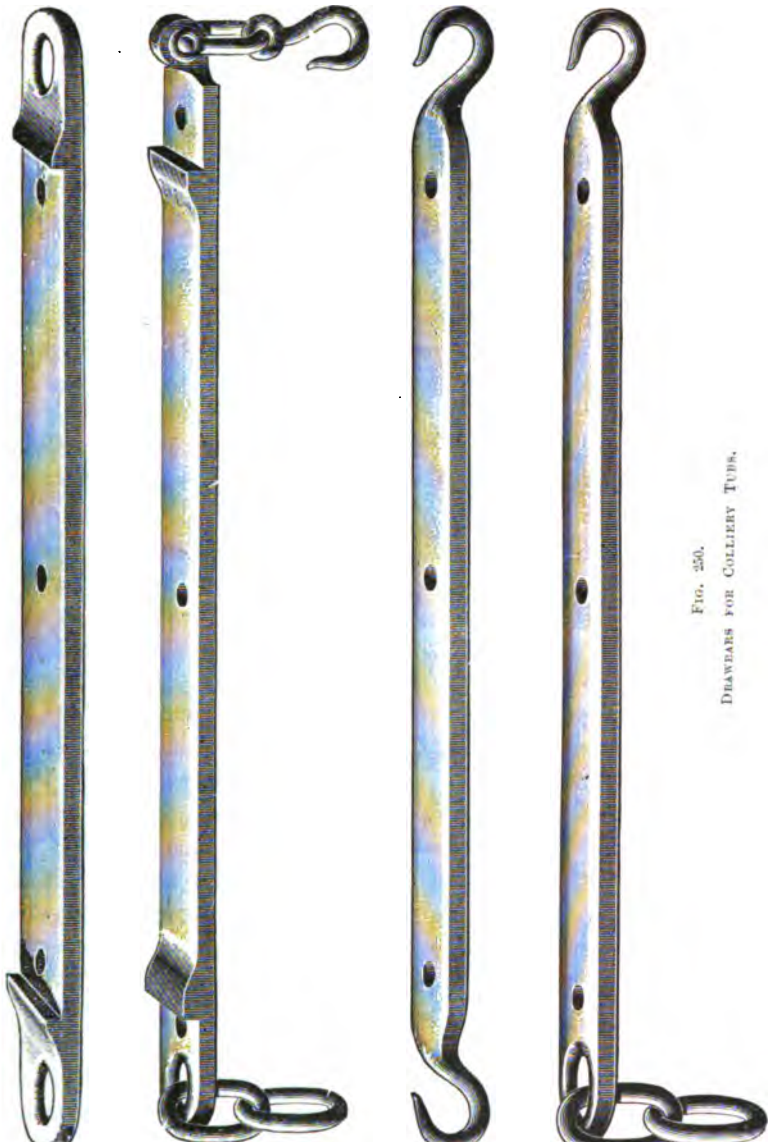


FIG. 250.
DRAWBARS FOR COLLIERY TUBS.

innumerable nondescript special rollers. They are also made with boxes, frames, or on stands, and Hadfield's standard frame

is a self-oiler which commands a ready sale, and gives absolute satisfaction. This Company provide numberless other items for mining purposes, amongst which may be mentioned grids for coal screens, pit turns and crossovers, elevator and conveyor buckets and links, hammers, picks, drill steel, shovels, etc. etc.

The (ERA) manganese steel having been found without a rival in any other direction for its resistance to the destructive elements of working conditions, has been, it is almost needless to add, utilised for colliery wheels. One firm's experience may be taken as a criterion. This firm, the Consett Iron Company Limited, have already had manganese wheels to the extent of something like 40,000 wheels, so the testimony is of undoubted value. The outcome of the adoption of (ERA) manganese steel indicates that wheels of this materal wear, to take the minimum, three times longer than any other steel wheels. Of course, in the majority of cases, the life is much greater than threefold, and this even where the severest tests are carried out on stiff gradients, coupled with a great deal of spragging. Manganese steel not only gives increased wear, but it has a wholesome freedom from breakages. It is a material that can be unreservedly recommended. It is giving remarkably good results for gearing for coal-cutter machines, and as these machines have evidently come to stay, there is a great future awaiting manganese steel in this particular connection. We may here remark that Hadfield's supply all those parts of the Diamond coal cutter which are made as castings.

Enough has been said to indicate how well adapted Messrs. Hadfield are to meet the requirements of colliery people, but it would be scarcely fair to depart from the subject without making some reference to the multitudinous articles which they send out in such large quantities to all parts of the world. Cylinders up to 27 feet long, made in the one length; rams; glands; containers for lead; riveter arms; press castings; gearing, large and small; spur, helical, and bevel teeth; locomotive castings, including wheel centres, horn blocks, guides, motion plates, axle boxes, dome rings, slide-bar brackets, etc.; together with carriage and wagon castings, to the specifications of the consulting engineers for the leading railways of the world; dynamo castings, made of special high

permeability steel. They make rings up to 12 feet diameter—Hadfield's patent "Resista," for high electrical resistance purposes. Then, for dredger work, there are buckets complete, lips, backs, tumblers, bollards, pistons, engine frames, crank webs, pins, and bushes; the parts that take the wear—that is, pins, bushes, and lips—being made, of course, of ERA manganese steel. In the erection of the bridges recently put up for the North-Eastern Railway Company, Hadfield's castings have been largely used, the roller bearings, rocker castings, etc., they supplied being of first-class description, both as regards quality of material and workmanship.

The latest section of work taken up is the manufacture of complete crushers, though the way to this had been paved for many years past by the vast and increasing demand there was for manganese steel in the form of crushing rolls, jaw faces and side cheeks, cones, concaves, etc. The main features of the crushers Hadfield's make are—the use of steel in place of cast iron for the frames, whereby increased strength is obtained, even though the frames are made so much lighter, with a corresponding advantage where transit is concerned, and the fact that all the wearing parts are made of ERA manganese steel. Hadfield's quickly took their place amongst the leading makers of complete crushers, and they have recently executed for South Africa what is believed to be the largest order yet placed at one time for crushers. They erect complete crushing plants of the gearing or belt-driven roll type, together with elevators, screens, etc.

The boom of the last few years in connection with the municipalisation and laying down of electric tramways gave rise to a new branch of steel castings at Hadfield's. This was the manufacture of tramway points and crossings, for which purpose ERA manganese steel was again to the fore. The firm have, at one time or another, put down on their own track floor, lay-outs, of more or less complicated design, for use on home and foreign tramways, amongst them being Sheffield, Salford, London (conduit system), Bournemouth, Lowestoft, Hull, Pietermaritzburg, Wellington, N.Z., and Tokio. Perhaps the best example of all is the junction in Fitzalan Square, Sheffield. In this city it was decided to have the "through" system—that is, the cars from one side of the city run to another side, there

being no actual terminus in the city itself. Most of the cars had to pass through Fitzalan Square, the lines at this point being a veritable network. The first week's trial of the through system revealed what appeared to be insurmountable difficulties at this junction. Smooth running was unattainable; the flanges were quickly broken off, the wheels and the rails themselves, in an incredibly short time, showed very appreciable signs of wear. The through system was a failure; or so said most people. But no, Hadfield's came to the rescue. They re-designed the lay-out, easing the curves, and it was decided that all the new parts put down should be made of ERA manganese steel, including the points, crossovers, and connecting rails. The result has been sweet running and entire satisfaction to all concerned—that is, unless Hadfield's are rather disappointed the wear is so slight as not to offer any prospect of new parts being wanted in the near future. They also supply the various tools required for tramway work, as well as a portable petrol rail grinder, which has the advantage over the electric grinder that it is not dependent on an outside source for the power to work. The grinder can also be connected with a drilling arrangement, so that it can both grind and drill the rails.

The East Hecla Works, employing about 4000 workmen, are replete with an admirable power house, from whence the energy is conveyed by means of electric cables for driving the machinery in the different departments; a pattern shop, covering 17,830 square feet, for the production, by the company's own workmen, of any type of pattern that may be required; and a well-fitted laboratory, where the strictest and most scientific attention is paid to that essential of essentials, the chemically correct constituents of the cast steel. Hadfield's are therefore in no small degree self-contained.

CHAPTER VIII.

PUMPING.

AMONGST the very earliest applications of steam power, and in some of the oldest records of the history of the steam engine, we find appliances for raising water from mine shafts and workings, and a most interesting chapter—indeed, a volume—might be written, setting forth the gradual development of the steam pumping engine from its earliest form, crude and primitive, to the present achievements of the hydraulic engineer.

One feature, which would appeal, perhaps, especially to readers of a book on colliery equipment, in the perusal of such a history is the fact that throughout its development the steam pumping engine has been closely identified with mines and mining. Doubtless some of us would have been better pleased if the conditions rendering pumping appliances necessary in our mines had been conspicuous by their absence. The fact, however, remains that, whilst mining operations are carried on, water, in greater or less volume, will have to be dealt with, and the colliery engineer finds it necessary to make himself practically acquainted with pumps and pumping engines, in all their recent and best developments.

Although it will be unnecessary to enlarge upon the early history of pumping appliances, it may be interesting to remember that the Cornish pumping engine of Watt derived its name from its general application in the mining county of Cornwall. It is interesting, too, to remember that the Cornish pumping engine of to-day, as represented by the improvements of Hathorn, Davey & Co., holds its own against all others in point of coal consumed and water raised.

But even long before the pumping engine of Watt (1769), Thomas Savery, in 1698, had invented and applied the

"miner's friend" for raising water by the direct application of steam. More than two hundred years have elapsed, but still we find the same principle serving useful purpose in the Pulsometer, which has figured largely in colliery operations in recent years.

Our present intention, however, is to confine our attention to modern pumping appliances, which, for convenience, may be divided into surface pumping engines and underground pumping engines, the former being erected at or near the mouth of the shaft, connected with pumps in the shaft by means of pump rods; the latter consisting of pumps and engines placed wholly in the mine, the pump and the engine forming part of the same machine.

Perhaps no better examples of surface pumping engines could be given than are afforded by the installations of Messrs. Hathorn, Davey & Co., of Leeds, who have placed at our disposal a good deal of useful information.

So far as the pumps themselves are concerned, in connection with this class of pumping engine, we have only to consider the bucket pump and the ram or plunger. Both have their advantages, and it is by no means uncommon to find both types embodied in the same pumping plant; such, indeed, appears to be the common practice of Messrs. Hathorn, Davey & Co. in deep shafts requiring more than one lift, in which case the bottom lift is a bucket pump, and the others rams or plungers.

THE BUCKET PUMP.

The action of a pump is, no doubt, well understood by most readers of a book of this class, but there are points deserving special mention, which will excuse the short description given here.

The pump itself consists of the bucket, the working or pump barrel, the suction valve or clack, the suction pipe and windbore with strainer, the pump stocks or delivery pipes, and the pump rods connecting the bucket with the engine.

The working barrel is of cast iron, truly bored, and of somewhat greater length than the maximum length of stroke. The bucket is practically a piston made to fit the working barrel, and fitted with clacks or valves, opening upward. Formerly the buckets were packed with leather or guttapercha;

latterly the metallic bucket has been adopted, which, as already remarked, is a piston, with recesses to receive brass or gun-metal piston rings. (*See fig.* 251.)

The bucket clacks are, as a rule, leather-faced "butterfly" clacks, opening upwards. Below the working barrel is the suction clack or valve.

In the open bucket lift the pump rods, which are usually of timber, work in the rising main or pump delivery, and this is the arrangement generally adopted. The alternative is the **H** piece, with a separate rising main, and the pump rod working through a gland and stuffing box.

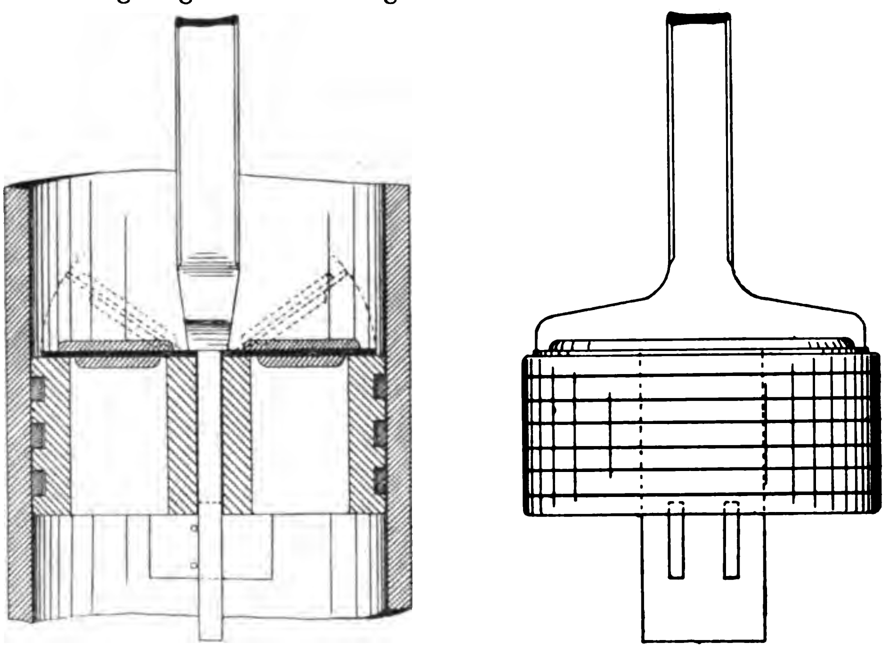


FIG. 251.

SHOWING A METAL-PACKED PUMP BUCKET, WITH BUTTERFLY CLACKS OR VALVES.

The action of the pump is simple enough. Assume the working barrel to be full of water, and the bucket at the top of its stroke; the descent of the bucket causes the water to pass through the bucket clacks, so that, on the return of the upstroke, the water is lifted by the bucket. Whilst the upstroke is in progress, the working barrel is filling with water from below, and it is the cause of this rising of the water to which it is proposed to give a little attention at this point.

Why does the water rise in the suction of a pump, and how far would the water in the suction pipe rise? As the bucket ascends in the working barrel, assuming it to be a good fit, there is a constantly-increasing space in the working barrel below, which, failing the admission of water or air, would be a vacuum. Since, however, the suction valve is free to open upward, and the atmosphere is pressing upon the surface of the water in the sump or pit, the water is forced by the atmospheric pressure to ascend the suction pipe and fill the pump barrel. Theoretically, if the pump barrel were of considerable length, attaining, say, a height of 40 feet above the water level, the water would continue to follow the ascending bucket for a total vertical height of about 34 feet. Having reached this point, however, the water would cease to follow the ascending bucket, and a vacuum, more or less perfect, would be produced above the water.

THE PRACTICAL HEIGHT OF A SUCTION LIFT.

Practically, however, the water would not reach the height stated, not because, as one reads in certain text books, the pipe joints cannot be made tight, but because all water met with naturally contains gases in solution, and as the pressure is diminished these gases are liberated, and, rising to the top of the water in the suction pipe, prevent the formation of the vacuum.

One might illustrate this liberation of dissolved gases very well by taking an ordinary bottle of soda water. Observed before the cork is removed, there is no visible evidence that a large volume of gas is dissolved in the water; the moment the pressure is relieved, however, by the removal of the cork, the dissolved gases escape, and innumerable bubbles are seen to form in the water.

In pumping practice it is a well-known fact that an excessive suction height is undesirable. On the other hand, the nearer the pump can be brought to its water the better, and in the high-speed pumps now becoming common with electrical motive power, it is desirable that the pump should have no height to lift the water by suction at all. With the surface-pumping engines, and bucket lifts, the suction should not exceed 27 feet, and 20 feet is better.

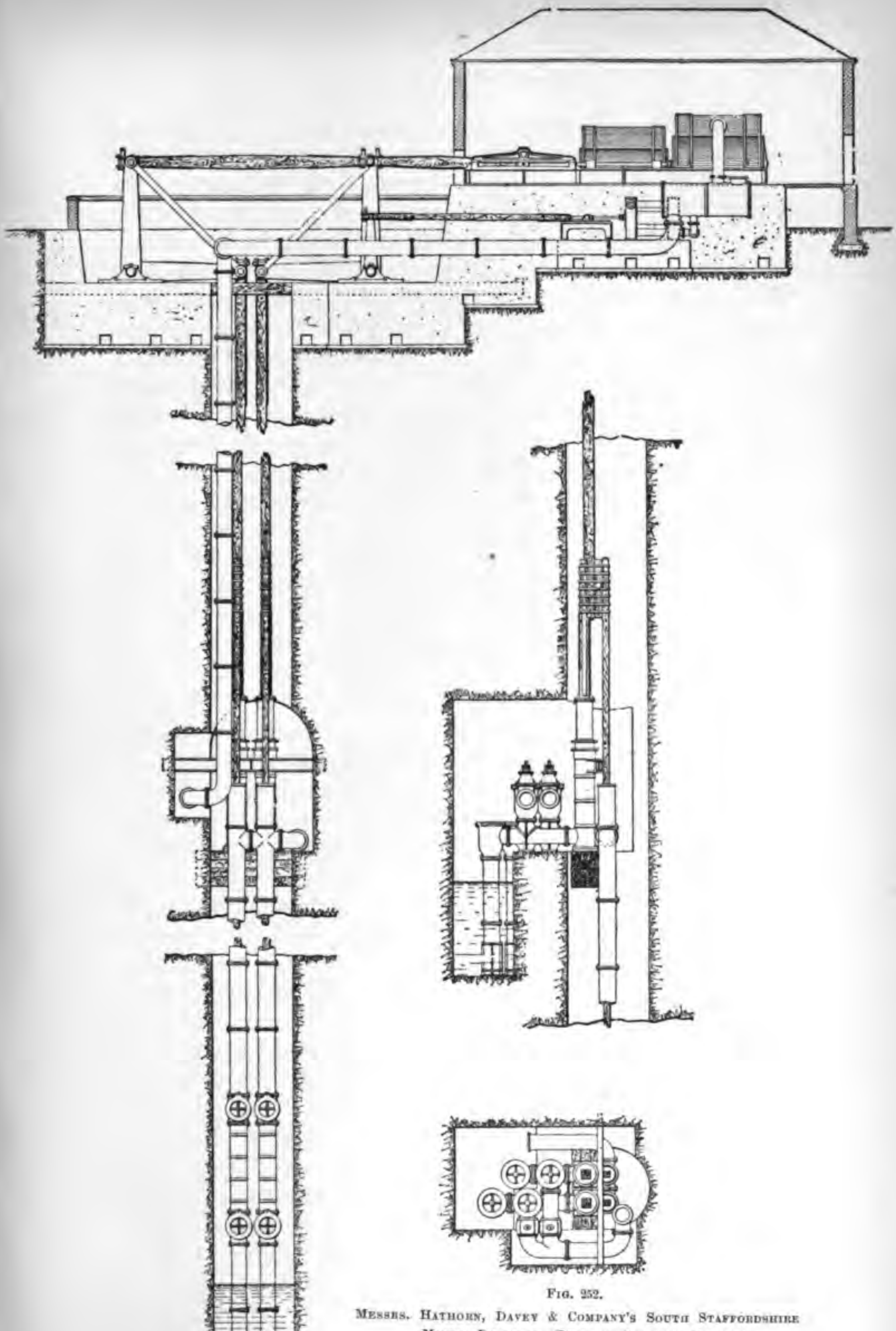


Fig. 252.

Messrs. Hathorn, Davey & Company's South Staffordshire Mines Drainage Type of Pumping Engine.

In the open lift bucket pump we have a direct straight line flow of water from the suction to the delivery. A bucket pump is essentially a single-acting arrangement, although in the open bucket lift there is a certain quantity of water, equal to the displacement of the pump rods, delivered during the downstroke.

Messrs. Hathorn, Davey & Co. advocate the application of the bucket for the bottom lift, especially if there is any possibility of the water rising in the shaft, and ram or plunger pumps for the intermediate lifts. Fig. 252 (*see page* 423) shows, in section, a horizontal compound condensing differential surface pumping engine, working two sets of pump rods. The bottom lift consists of two bucket pumps delivering into the lodge part way up the shaft at the point where two ram pumps are fixed; these take the water from this lodge and force it to the surface. A common delivery pipe connects with the two ram pumps, and since the rams move simultaneously in opposite directions, the delivery of water accompanies each stroke of the engine. The height of each lift does not, as a rule, much exceed 100 to 120 yards—at the most 150 yards.

THE RAM PUMP.

The ram or plunger type of pump is also illustrated in fig. 252. To all intents and purposes the ram is a solid cylinder, which at each downstroke displaces a volume of water equal to itself, forcing the water through the delivery valve up the rising main. At each upstroke the water rises up the suction pipe, through the suction valve, to fill the pump barrel.

The ram pump does not give that direct "straight through" movement of the water, but, on the other hand, working, as it does, through a gland and stuffing box, leakage can be more readily detected, and what is even more important, can be more easily packed and made good.

The illustration (fig. 252) represents the usual arrangement of bucket lift and ram lift, to deal with the water in two stages.

The valves used are either of the double-beat type, which have the advantage of affording an ample water passage without being unduly large, or the single-beat type. In the former, as the two parts are almost equal in area, the closing of the valve is not so violent as is the case with a single-beat valve.

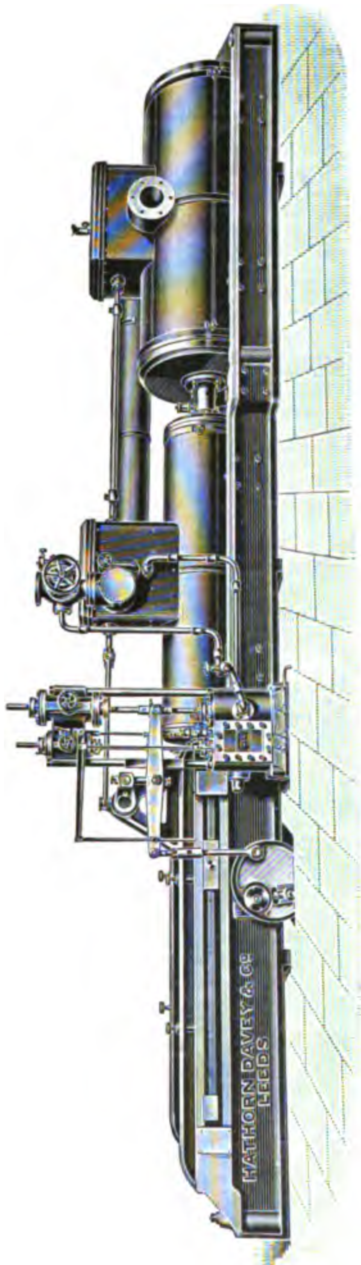


Fig. 253.
Horizontal Compound Differential Pumping Engine.

For sinking, and for dirty or gritty water, however, the old butterfly leather-faced valve is more suitable.

In the Hathorn-Davey pumps the suction valve of the bucket lift is so arranged that in the event of a breakdown, and the pump being submerged, it can be withdrawn by means of a fishing or grappling tool provided for the purpose.

Turning now to the engine, it is here that the relative high efficiency comes in, compared, that is, with underground pumping engines. The horizontal compound differential condensing engine, represented in fig. 253 (*see page* 425), illustrates the highest development in this type of pumping engine, and gives an efficiency, or duty, probably not approached, certainly not exceeded, by any other type of mine-pumping engine—that is, taking the steam consumed and the work done in foot pounds of water raised.

The low-pressure and high-pressure cylinders are placed tandem fashion, the former occupying the position farthest from the shaft. The high-pressure piston rod carries a cross-head working in the slide bars, and connects with the quadrants or bell cranks over the shaft, which divert the horizontal into a vertical motion; of course a single quadrant only would be required where only one line of pumps is applied. In the section (*see fig.* 252, *page* 423) there are, as before described, two sets of pumps.

DAVEY'S DIFFERENTIAL VALVE GEAR.

A special feature of this pumping engine, from which it takes its name "differential," is the mechanism for controlling the valves, both the steam admission and exhaust valves. This gear is shown in the engine view (fig. 253), and also on a larger scale in fig. 254. Its object is to positively control the motion of the engine, and adjust the steam pressure and exhaust so as to exactly correspond at any moment with the load. In the event, for example, of a miss-stroke (the pump missing its water from any cause) the motion of the engine is still perfectly uniform, and no risk is incurred of the piston rushing to the end of the cylinder and breaking the cover. The gear also includes a cataract arrangement, by which the necessary pause at the end of each stroke, before reversing, is controlled to a nicety.

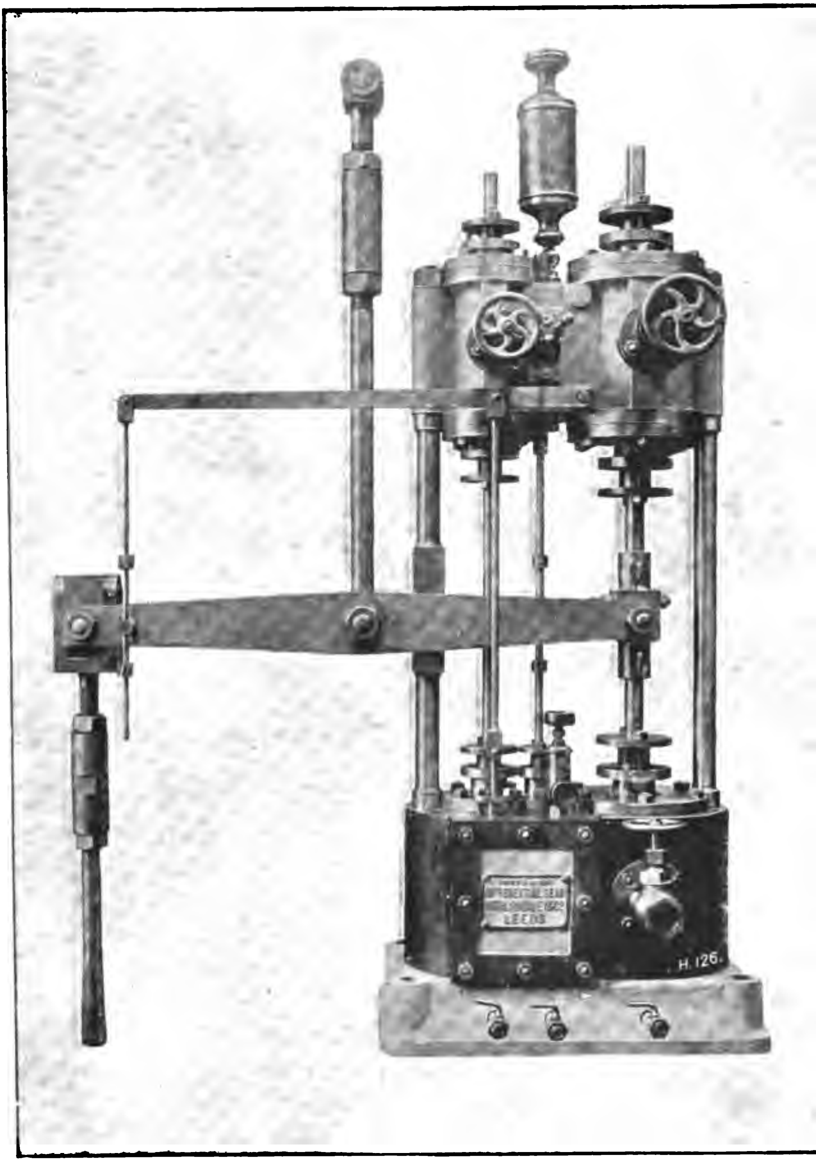


Fig. 254.

Davey's Differential Valve Gear.—The Steam Cylinders are below, the Cataract Cylinders above.

In the illustration (*see fig.* 254, *page* 427) two steam cylinders are shown at the bottom, the one to the right being the differential gear engine, the one to the left is a smaller engine whose function is to control the steam admission and effect the reversal of the differential gear engine. At the top are shown two cataract cylinders, one to each of these two engines, so that their speed can be adjusted as required.

It will be seen that the gear engine actuates one end of a lever or link; the other end of this link receives its motion from the main engine. Attached to the middle of this link is the rod which, through suitable mechanism, actuates the valves of the main engine.

Now it will be evident that this link is a lever which has no fixed fulcrum, and if the ends were moved in opposite directions at the same speed, no movement would be imparted to the middle point. As a matter of fact, however, the two ends do not move at equal speeds, nor do they always move in opposite directions. Whatever may be the movement of the two ends, however, it will be seen that the central point must have a mean or differential motion between the two, and the arrangement is such that the valves are opened when the link centre is moved in the direction in which the gear engine is moving, and closed when the centre of the link moves in the direction in which the main engine tends to move it. The gear engine, as already mentioned, is controlled by a cataract, and its speed can therefore be adjusted so as to move at a rate which will give the necessary valve opening when the main engine is working at the proper speed; but should this proper speed be exceeded—either because the steam pressure is increased, or because the pump has missed its water—the main engine overtakes the gear engine, and tends to cut off or throttle its own steam supply by closing its valves.

By means of the smaller cylinder to the left of the gear cylinder the amount of pause at the end of each stroke may be adjusted to any desired length.

The provision of this pause—to enable the pump "to collect its thoughts," as the late author used to express it—is of the utmost importance in these large and heavy pumping engines, with their long lengths of massive pump rods and heavy water columns. An immediate reversal of motion, such as would be

provided with a flywheel motion, would result in the pounding of the valves upon their seats, and a succession of violent shocks all the time the pump was in motion. For the same reason this type of pump has a fairly long stroke (from 6 to 10 feet) and slow speed, although the longer stroke permits a higher speed than a short stroke, but, of course, fewer reversals per minute. A good practical rule is to multiply the square root of the stroke in feet by 80, thus, a pump having a stroke of 4 feet, $\sqrt{4} \times 80 = 160$ feet per minute.

Some years ago the present writer had the opportunity of inspecting the pumping plant at a group of iron ore mines in North Lancashire, where he had the privilege and pleasure of meeting the engineer, Mr. James Davison, whose practical knowledge of pumps and pumping engines would go a long way towards filling a volume of the dimensions of this work. Being responsible for plant raising from 8,000,000 to nearly 10,000,000 gallons per twenty-four hours, it is not to be wondered that Mr. Davison's pump lore was of an exceptionally comprehensive character.

The work was divided amongst seven pumping engines, although not equally, as the lion's share seemed to be taken by two Hathorn-Davey pumping engines, which were together raising not far short of a quarter of a million gallons per hour. Both engines had a stroke of 10 feet, and the rams were 20 inches diameter. One had cylinders respectively 33 and 60 inches diameter, and worked two 20-inch rams, raising the water 400 feet in one lift; the other had cylinders 38 and 66 inches in diameter, and worked two lifts of 20-inch rams to a total height of 560 feet.

In connection with the South Staffordshire Mines' Drainage Commission, there is a large Davey differential pumping engine, raising water from a depth of 490 feet. The steam cylinders are 52 and 90 inches in diameter respectively, high and low pressure, and the rams 27 inches diameter, working with a stroke of 10 feet, and delivering 496 gallons at each stroke, equal to about 5,000,000 gallons per 24 hours.

THE DUTY OF PUMPING ENGINES.

Before passing to the consideration of underground pumping engines it may be useful, at this point, to explain the meaning

of a term which originated in the days of the old Cornish pumping engines in the county of that name. A good deal of healthy rivalry prevailed amongst the engineers and mine owners in the matter of pump efficiency, and, as a means of comparing the work and efficiency of one pumping plant with another, a standard was adopted, which is still used to some extent, but not so generally as formerly. The comparison adopted was the number of foot pounds, expressed in millions, in water raised, per "bushel" of coal burnt. As the bushel was a somewhat elastic quantity, the hundredweight—112 pounds—has been adopted. Expressed in this way the duty of the Hathorn-Davey compound condensing differential pumping engine has been shown to be as high as 53—that is, 53 millions of foot pounds in water raised per one hundredweight of coal burnt.

As different classes of coal have different calorific power, this system is, after all, scarcely satisfactory, and is not often adopted at the present time. The most accurate method is to indicate the engines in the usual way, ascertain the steam consumption, and calculate the work done in water raised.

In point of efficiency-economy there can be little doubt that a high-class surface pumping engine excels, whilst there is also the advantage that the engine itself cannot possibly be drowned by an inrush of water overpowering the pumps.

On the other hand, the first cost is much higher both for engines, pumps, rods, shaft fittings, engine house, and foundations, and unless a shaft can be devoted entirely to pumping, the presence of heavy and bulky pumping plant in the pit is not very desirable. Often it happens, in a heavily-watered district, that a pumping shaft is set apart for the drainage of a considerable area, and under these conditions probably no better arrangements could be made, and no more highly-efficient equipment provided, than is represented by the compound condensing differential pumping engine as above described.

USEFUL FIGURES IN CONNECTION WITH WATER AND PUMPING.

It may be convenient, at this point, to introduce some useful figures which, from time to time, will be required in the course of the examples given and calculations worked out in the succeeding pages. These figures are all deduced from the fact

that an imperial gallon of water (277·274 cubic inches), at a temperature of 62 degrees F., weighs exactly 10 pounds.

From this we get the following:—

*1 cubic foot of pure water weighs 62·32102 pounds.

*1 cubic foot contains 6·232102 gallons.

1 cubic inch weighs ·03607 pounds.

1 foot head vertical = ·43278 pounds per square inch, which, for practical purposes, may be taken as ·433 pounds per square inch.

Approximately, cubic feet per minute multiplied by 9000 equals gallons per 24 hours.

Two useful figures in connection with pumping calculations, and, indeed, all calculations relating to water contained in or flowing through cylindrical pipes, are the following: ·034 and ·34, which express respectively the capacity in gallons and the weight in pounds of a cylinder 1 inch in diameter and 12 inches long; thus, 1 inch diameter × 12 inches long = ·03399 gallons, say ·034, and this quantity of water weighs ·3399 pounds, say ·34. These figures, used in connection with pump calculations, save a considerable amount of time and labour, as the following examples will show:—

Example: What quantity of water, in gallons, and what weight in pounds, is contained in 200 yards of 10-inch diameter pipes?

The ordinary and direct mode of procedure would be a rather tedious calculation in which we square the diameter in inches $= 10 \times 10 = 100$, and multiply by $·7854 = 78·54$ square inches area. We now multiply this by the total length of the pipe in inches, or $78·54 \times 200 \times 36 = 565{,}488$ cubic inches, which we have to divide by 277·274 to bring to gallons $= 2039·4$ gallons, or multiplied by $10 = 20{,}394$ pounds.

Now, making use of the figure ·034, which represents the capacity in gallons of a cylinder 1 foot long and 1 inch diameter, and remembering that the areas of circles increase as the square of their diameters, we proceed as follows:—

Square the diameter in inches, multiply by the length in feet, and by ·034: $10 \times 10 \times 600 \times ·034 = 2040$ gallons, or 20,400 pounds.

The slight difference is of little importance; it is accounted

* Generally taken, for practical purposes, as 62·5 pounds and 6·25 gallons respectively.

for by the fact that we have slightly increased the constant ·034, which should really be ·03399.

The same rule can be applied to calculate the *total* pressure (not the pressure per square inch) on a ram, or on the bottom of a pump column, due to a given head of water.

Example: A column of pipes 225 yards vertical filled with water; what is the total pressure upon a ram at the bottom, 8 inches diameter? $8 \times 8 \times 225 \times 3 \times {\cdot}34 = 14{,}688$ pounds total pressure on the ram.

To calculate the delivery of a pump in gallons per minute, this figure (·034) saves a considerable amount of labour. The rule is: Square the diameter of the pump in inches, multiply by the stroke in feet and by the number of strokes per minute, *one way*, for a single-acting pump, or the total number per minute, each way, for a double-acting pump, and by ·034.

Example: A single-acting ram pump, 10 inches diameter, 15-inch stroke, making 40 strokes per minute each way: $10 \times 10 \times 1{\cdot}25 \times 40 \times {\cdot}034 = 170$ gallons per minute.

If the pump had been a double-acting ram we should have multiplied by 80 instead of 40, and the result would be 340 gallons per minute.

If the pump has a flywheel motion the speed will generally be given in revolutions per minute, in which case, for a single-acting pump, multiply the diameter squared by the stroke in feet by ·034, and by the number of revolutions per minute; or if *double* acting, by *twice* the revolutions per minute.

In a three-throw pump, with three single-acting rams, multiply by three times the revolutions per minute.

SLIP IN PUMPS.

In all the above it is usual to make a deduction from the calculated output of the pump, from 5 to 10 per cent—in a good pump it should not exceed 5,—to allow for the escape of water through the valves before they have time to close, and also to allow for any other possible leakage.

UNDERGROUND PUMPS AND PUMPING ENGINES.

Turning our attention, now, to underground pumping engines, it is, of course, evident that wherever the pump is fixed it must be comparatively near the water with which it

has to deal; in fact, the nearer the better—the suction lift should be as short as possible.

These pumping appliances may be variously classified, as, for example, positive displacement pumps and momentum pumps. The former would include ram pumps, piston pumps, bucket pumps, and pulsating pumps; the latter includes centrifugal and turbine pumps. The former alternately fill and displace a definite volume of water; the latter act upon the principle of imparting to a volume of water a high velocity, by virtue of which it is capable of ascending to a considerable height.

Pumps are either reciprocating or rotating. Displacement pumps are generally of the former class, although rotary displacement pumps are not unknown; momentum pumps are generally rotating, although at least one with a reciprocating motion has been brought under our notice.

Reciprocating motion pumps may have a crank and connecting rod motion with flywheel, or may be directly connected with the piston rod of the actuating engine; these are called direct-acting pumping engines.

Electrically-driven pumps have, of necessity, the crank and connecting rod motion, unless they be of the rotary type.

TYPES OF RECIPROCATING PUMPS.

The following short descriptions are perhaps scarcely necessary, but they serve to clearly distinguish the features of the pumps in use, and to indicate their particular advantages.

The bucket pump has been fully described already in connection with the surface type of pumping engine, to which it is specially adapted. It is, indeed, scarcely applicable to the underground pumping engines; it is essentially a single-acting arrangement, and is almost invariably applied as a vertical arrangement.

The ram pump, sometimes called "the plunger," is also essentially a single-acting arrangement. We often speak of a double-acting ram pump, but in all cases there are in reality two pumps with the ram operating between them. (*See fig.* 255, *page* 434.)

The ram pump may be vertical or horizontal, suction or force pump. Ram pumps are internally packed or externally

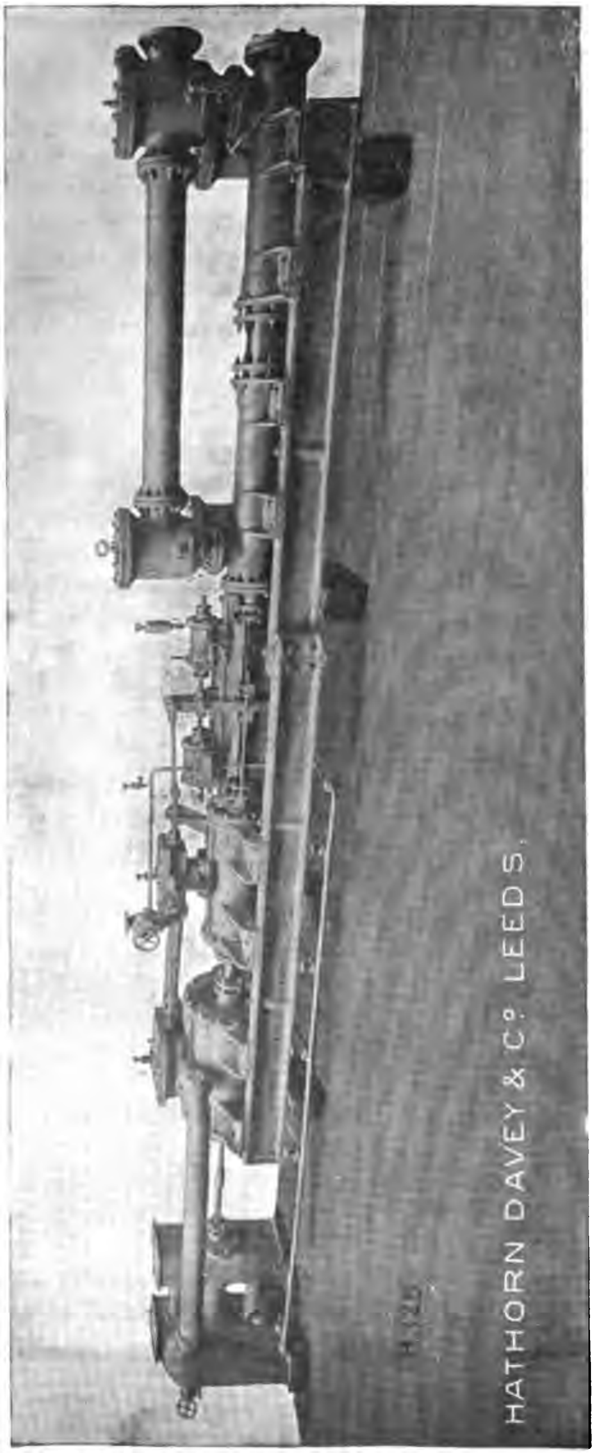


Fig. 255.

A Horizontal Compound Condensing Differential Underground Pumping Engine, with Double-Acting Ram.

packed. For mining purposes the former would rarely be used; indeed, the great feature of the externally-packed ram is, that any leakage can at once be seen and remedied without taking the pump to pieces.

In the double-acting arrangement one ram may be employed with each end operating a separate pump, or two rams and two pumps working together as one machine. In the former arrangement the pump rod passes through one pump and connects with one end of the ram only (fig. 255), thus diminishing the effective area of the ram to this extent. This is a matter of some importance in a pump working under a heavy pressure, as the following example will show:—

A pump delivering water to a height of 1000 feet has a pump rod of 3 inches diameter, 7·068 square inches area, on one side only. The pressure in pounds per square inch is found by multiplying the head in feet by ·433, therefore, $1000 \times {\cdot}433 \times 7{\cdot}068 = 3060$ pounds, or 1·36 tons more pressure on one end of the ram than on the other; or, applying the figure ·34, as already instanced: $3 \times 3 \times {\cdot}34 \times 1000 = 3060$ pounds.

In pumps working under a heavy pressure the arrangement should, therefore, be double-acting with both ends of the ram of equal area. In three-throw pumps the rams are not necessarily double-acting—they are, indeed, more generally single-acting—the three-crank arrangement giving a fairly uniform load.

The piston pump is essentially a double-acting arrangement. It is scarcely suited for heavy pressures, on account of the difficulty in keeping the piston tight, and the still greater difficulty of making repairs. The only repair possible is by taking the pump to pieces, re-boring the working barrel, and making a new piston. For moderate pressures and perfectly clean water, however, they answer well enough, and the writer is familiar with a pumping engine, having a pair of double-acting piston pumps, which has been in constant operation for over thirty years, during which time it has only been found necessary to re-bore the pump barrels once. The pistons of piston pumps are either provided with rings or other arrangements for making them tight in the barrel, or, on the other hand, they may be simply smooth cylinders, with three or four small grooves or recesses cut round the piston, which

materially affect the working of the pump in preventing the slip or leakage of water past the piston. Why this should be so we do not attempt to explain, but it nevertheless appears to be a fact.

FLYWHEEL PUMPS.

Almost indispensable in connection with engines, and most reciprocating machinery, the flywheel—except in special types to be described later—is scarcely an ideal feature in a pumping engine. The function of a flywheel in an engine, for instance, is to store up energy, and govern, to some extent, the working of the engine, tending to check any sudden variation of speed, and helping the engine over the dead centre.

Consider for a moment the action of a single-cylinder horizontal engine. At the commencement of a stroke the piston is powerless, because the piston rod, connecting rod, and crank are all in one straight line. The energy stored up in the flywheel (we are assuming the engine to be in motion) carries it past this critical point. At the midstroke the piston is in the most powerful position, and tends to urge the engine forward with what might be a jerky motion, were it not for the steadying effect of the flywheel.

Desirable as the latter feature may be in the working of a pumping engine, it is just as undesirable that the reversal of motion at the end of the stroke should be that immediate reversal provided for by the flywheel, and, as a rule, pumping engines are direct-acting, without the flywheel motion. The immediate reversal at the end of each stroke does not give the pump time, as we expressed it before, to "collect its thoughts;" the result is a pounding of the valves upon their seats, and excessive shocks and strains generally, whilst the slip of water is excessive.

DIRECT-ACTING PUMPING ENGINES.

In the direct-acting pumping engine the steam cylinder and pump are in one straight line, and the piston rod connects directly with the pump rod. Such an arrangement may consist of one steam engine, with either a single or double-acting pump (*see fig.* 255, *page* 434), or we may have a pair of steam cylinders side by side, working two single or double-acting pumps, also side by side.

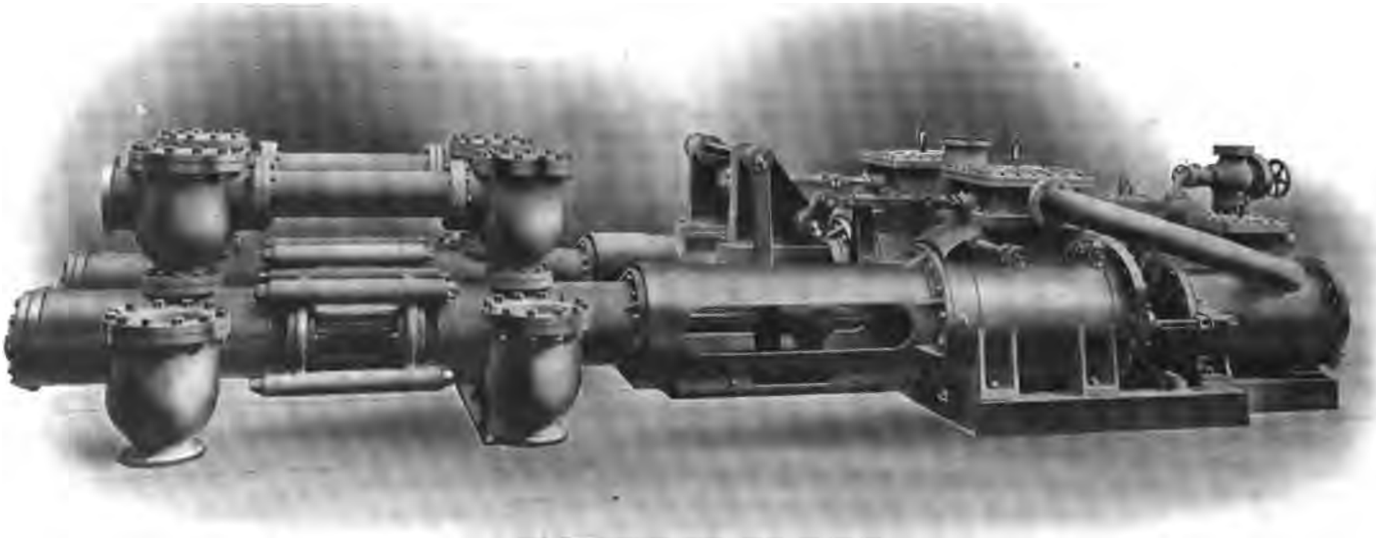


FIG. 256.

A HORIZONTAL DUPLEX COMPOUND DOUBLE-ACTING RAM PUMPING ENGINE, BY MESSRS. FRANK PEARN & CO. LIMITED.—CYLINDERS 23 INCHES AND 26 INCHES BY 3-FOOT STROKE RAMS 12¼ INCHES DIAMETER; DUTY 60,000 GALLONS PER HOUR, 420 FEET VERTICAL.

Fig. 257.

A Horizontal Triple-Expansion Duplex Double-Acting Ram Pumping Engine.—Cylinders 23 Inches, 36 Inches, and 54 Inches by 6-foot Stroke; Rams 10¼ Inches Diameter. Duty 60,000 Gallons per Hour, 1820 Feet. Messrs. Frank Pearn & Company Limited.

Advantage is taken of the latter arrangement to obtain the peculiar action common to what are called "duplex" pumping engines.

Messrs. Frank Pearn & Company Limited, of West Gorton, Manchester, are not without fame, where pumps are concerned, in the mining world, as the two excellent examples shown in fig. 256 (*see page* 437) and fig. 257 will suggest.

The former is a horizontal compound duplex double-acting ram pumping engine. There are four steam cylinders—namely, two high-pressure, 23 inches in diameter, and two low-pressure, 36 inches in diameter. The rams are 12½ inches in diameter, and the stroke is 3 feet. As a matter of fact, there are two compound direct-acting pumping engines side by side, combined to form what is known as a duplex pumping engine. This engine is one of a duplicate set installed at the Maypole Colliery of the Moss Hall Company, near Wigan. It was designed for a duty of 60,000 gallons per hour delivered to a vertical height of 420 feet.

It will perhaps be useful at this point to work out the capacity of this pumping engine, to show the application of the short rule already given. We shall assume a pump speed of 100 feet per minute: $12{\cdot}5 \times 12{\cdot}5 \times {\cdot}034 \times 100 = 531{\cdot}25$ gallons per minute each pump, or, say, 1060 for the two double-acting rams.

It will be noticed that this is the arrangement of double-acting ram in which the pump rod passes through one pump barrel and reduces the effective area of the ram on that side. In the other illustration (fig. 257) we have the alternative and better arrangement, where two separate rams are provided for each pump, making four rams in all. The two rams of each pump are coupled by means of outside rods, thus leaving the full area of the rams effective.

This pumping engine (fig. 257) is a horizontal triple-expansion duplex double-acting ram pumping engine. The high-pressure, intermediate, and low-pressure cylinders, two of each, are respectively 23, 36, and 54 inches in diameter; the rams are 10½ inches, and the stroke 3 feet. Steam is delivered to the engine at a pressure of 120 pounds per square inch. It was designed for a normal capacity of 60,000 gallons per hour against a head of 1320 feet.

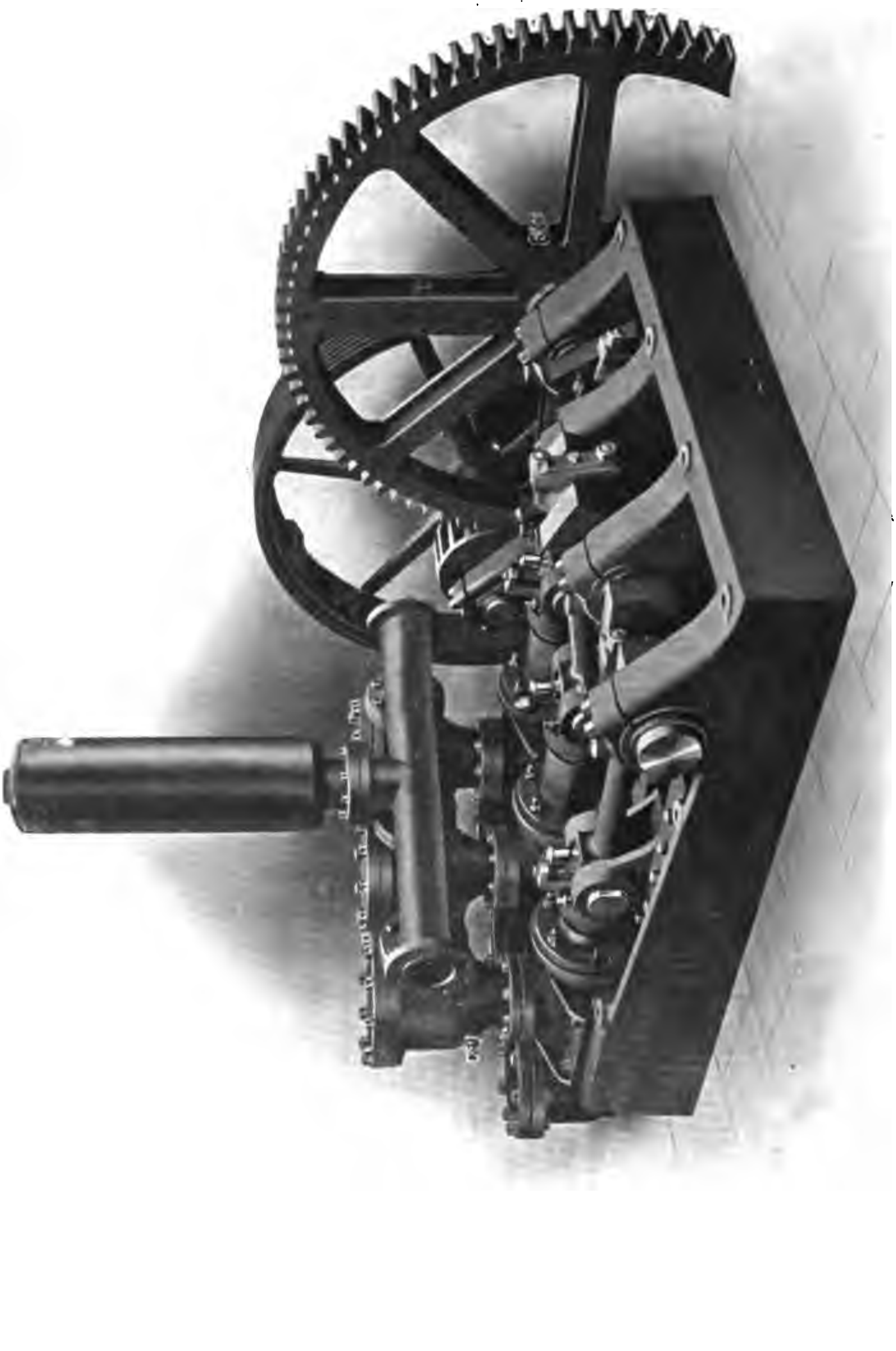


FIG. 288.—A THREE-THROW RAM PUMP, WITH GROOVED PULLEY FOR DRIVING FROM AN ELECTRIC MOTOR. MESSRS. F. PEARN & COMPANY LIMITED.

The peculiar feature of the duplex pumping engine is not difficult to explain, and it lies in the fact that the steam admission of one cylinder is controlled by the working of the other engine. We will call the steam cylinders of a simple duplex pumping engine No. 1 and No. 2 respectively, and we shall suppose that No. 1 is in motion; No. 2 is stopped, but just as No. 1 approaches the end of its stroke it operates the slide valve of No. 2, and sets it in motion. No. 1 now has a

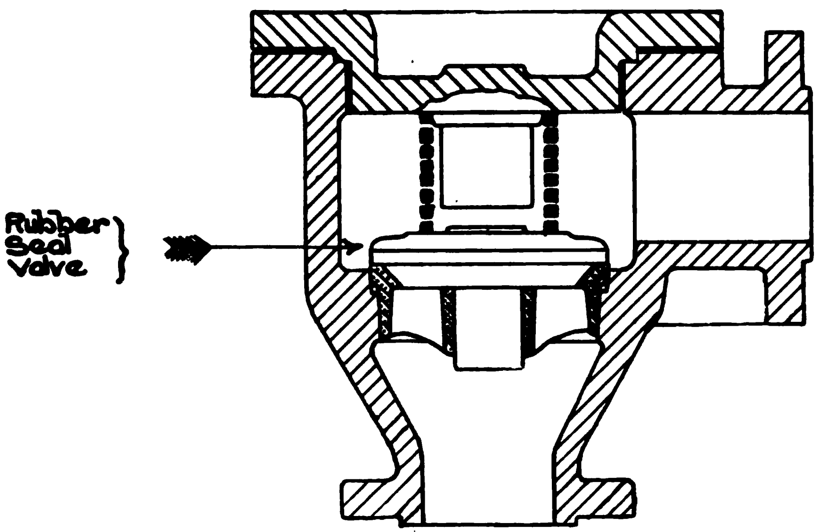


FIG. 259.

SHOWING DETAIL OF PUMP VALVE.

brief rest, to be in turn set in motion in the reverse direction just before No. 2 comes to rest. These pumping engines give a steady delivery of water, work smoothly, and provide that necessary pause at the end of each and every stroke.

Messrs. Frank Pearn & Co., like many other pumpmakers catering for colliery requirements, have recognised that steam is no longer the only motive power applicable for pumping, and they have designed and erected a number of electrically-driven pumps, some of which we are enabled to illustrate.

Fig. 258 is a good example of a strongly-designed three-throw pump, with rams 8¼ inches in diameter, 12-inch

stroke, to be driven by rope gearing from a motor. The grooved rope pulley and the large spur wheel are cast in halves; the teeth in the latter and in the pinion are machine-cut. This pump was designed to deliver 250 gallons per minute to a vertical height of 720 feet.

Here, again, we may usefully apply our rule. Assume a

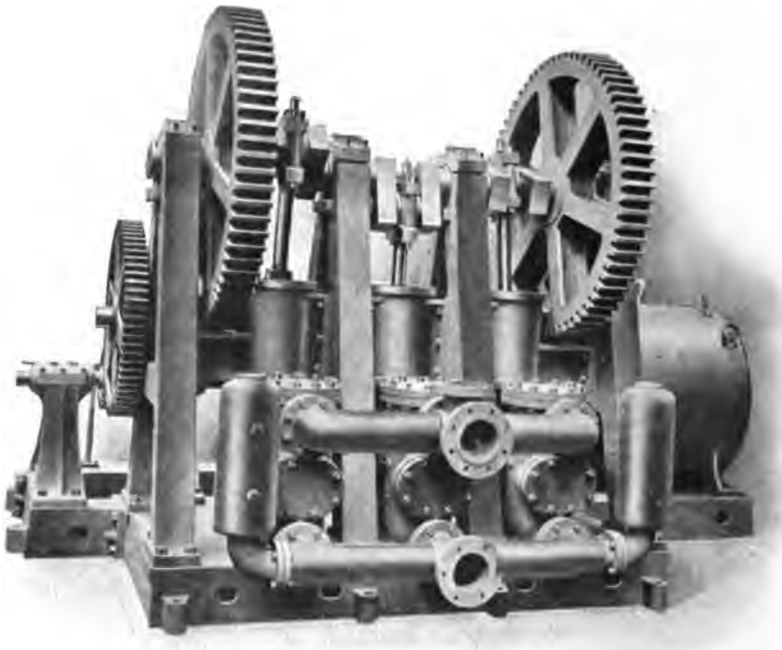


FIG. 260.
MESSRS. F. PEARN & COMPANY'S VERTICAL THREE-THROW ELECTRIC PUMP.

speed of 80 feet per minute, and, as the pump has a stroke of 12 inches, this means 40 revolutions per minute of the three-throw crank. In this case the pump—that is, each ram—is single acting, we therefore multiply by *half* the pump speed; thus, $8{\cdot}25 \times 8{\cdot}25 \times {\cdot}034 \times 40 =$ say, 92 gallons per minute for each ram, multiplied by $3 = 276$ gallons per minute; less slip, equals, say, 250 to 260 gallons per minute.

Fig. 259 (*see page* 441) shows a section through one of the valves of this pump.

Pumps, like haulage machinery, may be driven electrically, either with a rope or belt drive, or by direct gearing.

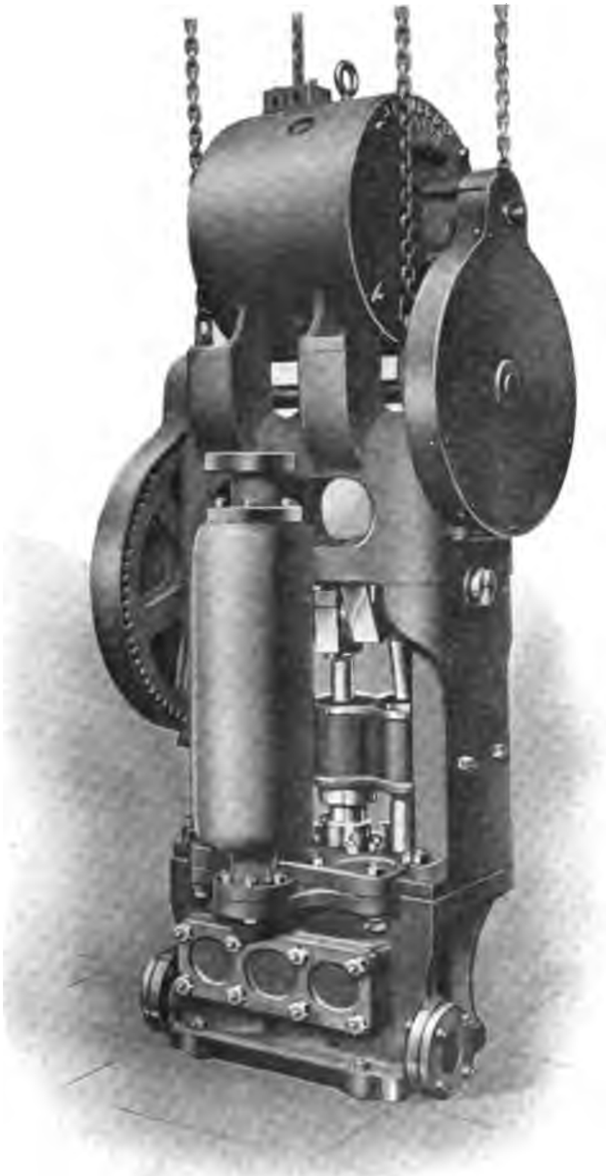


FIG. 261.
PEARN'S THREE-THROW ELECTRICAL SINKING PUMP.

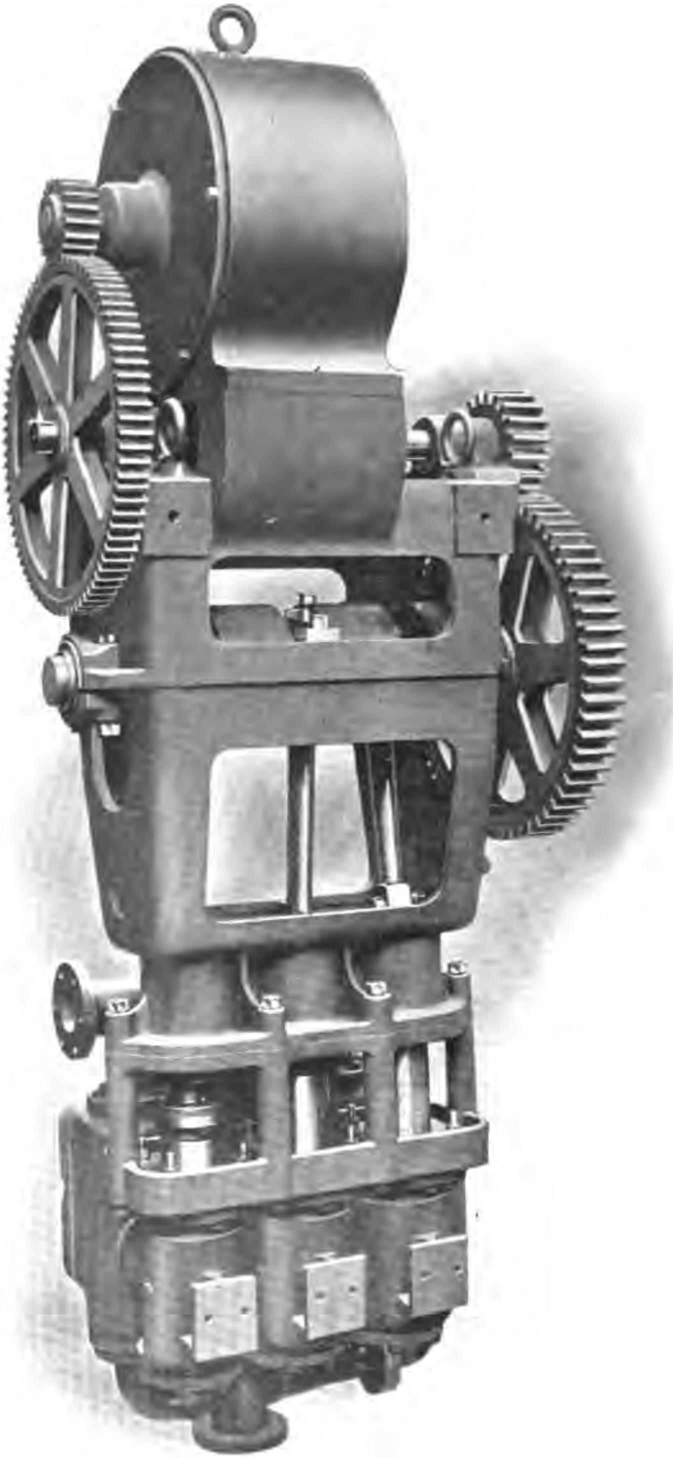


FIG. 262.—MESSRS. PEARN'S VERTICAL THREE-THROW ELECTRIC SINKING PUMP, ARRANGED FOR SUBSEQUENT WORKING AS A HORIZONTAL PUMP.

Fig. 263.—Showing the Pump Illustrated in Fig. 262, arranged as a Horizontal Pump. Messrs. F. Pearn & Company Limited.

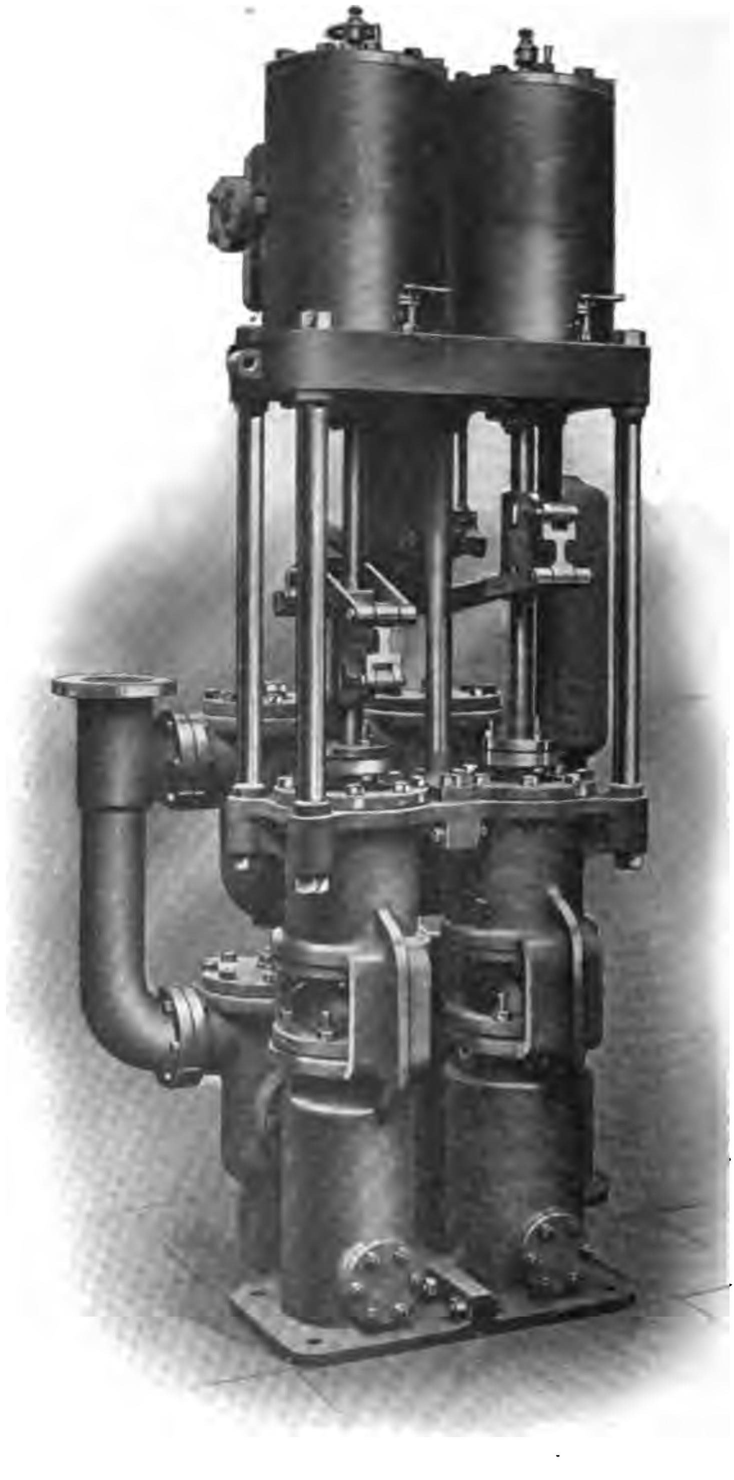


FIG. 264.—PEARN'S VERTICAL DUPLEX DOUBLE-ACTING RAM HIGH-PRESSURE BOILER FEED PUMP, WITH PATENT SYSTEM OF PACKING THE RAM.

Fig. 260 (*see page* 442) shows a vertical arrangement. The three-crank shaft has a spur wheel at each end; the intermediate shaft has both a pinion and a spur wheel at each end, the former gearing into the wheel on the crank shaft, the latter being driven by the pinion on the motor shaft, which, like the other shafts, extends across the whole width of the pump, and carries two pinions. The object of this duplicating of the train of gearing is to provide an equal turning effort on the crank shaft.

The particular pump illustrated (fig. 260) has rams 10¼ inches diameter and 15-inch stroke. It was designed to raise 25,500 gallons per hour to a height of 600 feet, for which purpose it was fitted with a 125 brake horse power motor. This works out to 62 per cent efficiency for the pump and gearing and the friction of the water in the pipes.

Fig. 261 (*see page* 443) shows a small 20-horse power sinking pump for suspending in the shaft with chains. The rams are 4 inches diameter by 6-inch stroke, and the capacity 40 gallons per minute to a height of 300 feet.

Figs. 262 and 263 (*see pages* 444 *and* 445) show a useful arrangement of pump primarily intended as a sinking pump, to be suspended in the shaft in the usual way. Provision is made' however, for bolting additional castings to the frame of the pump below the motor, and also to the pump barrels, so that after the sinking operations are completed the pump may be permanently installed as a horizontal arrangement.

The photograph represents a pump with 5½-inch rams, 8-inch stroke, fitted with a motor equal to a duty of 120 gallons per minute to a height of 330 feet.

MESSRS. JOSEPH EVANS & SONS' PUMPS.

Messrs. Joseph Evans & Sons, of the Culwell Works, Wolverhampton, are well-known makers of pumping appliances for colliery work, and their name as pumpmakers has always been regarded as a guarantee of sound workmanship. For many years they have specialised the manufacture of pumping machinery of every description, and particularly those adapted to the requirements of collieries and mines.

In addition to the ordinary direct-acting and flywheel pattern of pumps, they have specialised the manufacture of suspended steam sinking pumps. Fig. 265 (*see page* 448) represents their

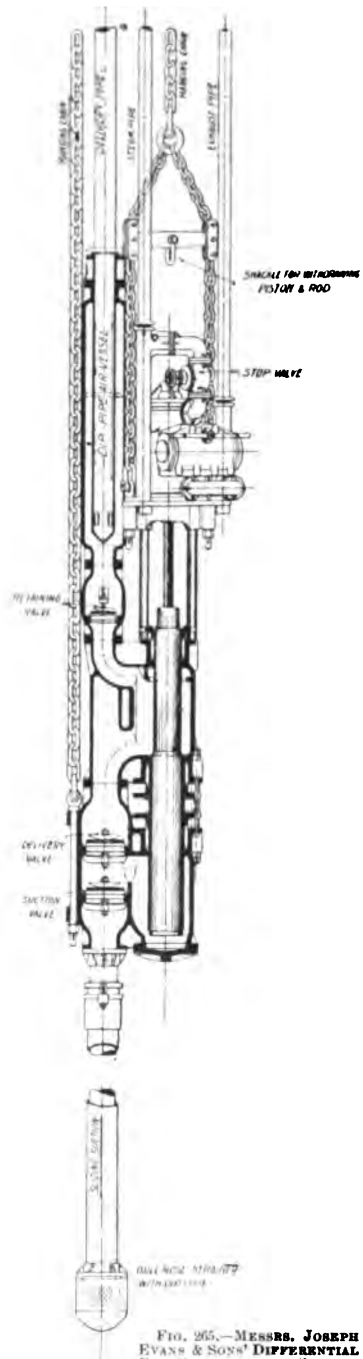


FIG. 265.—MESSRS. JOSEPH EVANS & SONS' DIFFERENTIAL RAM STRAIGHT-LINE SINKING PUMP.

differential ram straight-line Cornish sinking pump, the pump end being shown in section. From the illustration it will be observed that the steam piston is cottered direct to the upper end of the pump ram, the latter being shouldered down, the lower portion being approximately double the displacement area of the upper portion. This arrangement of ram makes a very convenient one, being entirely central and in direct line with the steam cylinder, thus avoiding any side strain, whilst by removing the bottom cover, and taking out the steam piston and piston rod, the ram can be lowered by means of a chain through the bottom of the pump for skimming up when worn, or for the purpose of replacing with another ram, thus obviating the removal of the whole pump from the shaft.

It will also be noticed that in this arrangement of pump only one suction and one delivery valve are required. The enlarged portion of the ram is single-acting, so far as the suction stroke is concerned, but the delivery, owing to the shouldered portion of the ram alternately passing into and retiring from the upper pump chamber, gives a double-acting and practically continuous dis-

charge. A retaining valve is a necessity with this type of pump on heavy lifts, in order to relieve the pump of any shock should the bottom ram miss the stroke, and, of course, it also serves to retain the water in the rising main when it is desired to examine valves or otherwise disconnect any portion of the pump.

The dip-pipe air vessel is also a special feature, and, as will be observed, it is arranged snugly by the side of the steam cylinder, and forms a portion of the rising main. It may be observed that in working it is very necessary to ensure this air vessel being charged with air. A snifting cock is fitted on the pump for the purpose of taking in a little air at each stroke, in order to keep this air vessel charged.

Messrs. Evans recommend chains for suspension of their sinking pumps, as they have found from experience that there is less stretch and spring on chains than ropes, whilst, by having the long-link pattern of chain, it is a most convenient method of securing the pump in any desired point by passing a steel bar through any particular link of the chain, and resting it upon the cross girders at the surface. The chain arrangement is also very convenient for the attachment of coupling shackles to the lifting blocks. There is also a difficulty in gripping wire rope to carry heavy weights satisfactorily. A number of clips would have otherwise to be fixed on the ropes, which would take a long time to fix on and remove, whilst they usually cause damage to the rope.

Figs. 265 and 266 (*see page* 450) show a typical installation of these sinking pumps as actually carried out at the sinking of the Gedling Colliery, near Nottingham, and show the sinking headgear, combined with the pump hanging gear, and arranged so that four large straight-line sinking pumps could be suspended and worked in an 18 feet 6 inches diameter shaft. This installation was actually carried out, and sinking successfully accomplished, through a very large feeder of water, amounting to, at times, from five to six million gallons of water per 24 hours, and to a depth of 150 yards.

It will be noticed in the Evans system of suspended sinking pumps no attachment to the sides of the shaft of any kind is required. The whole plant, including the pump, pipes, chains, and accessories, is slung from the top, and raised and lowered as

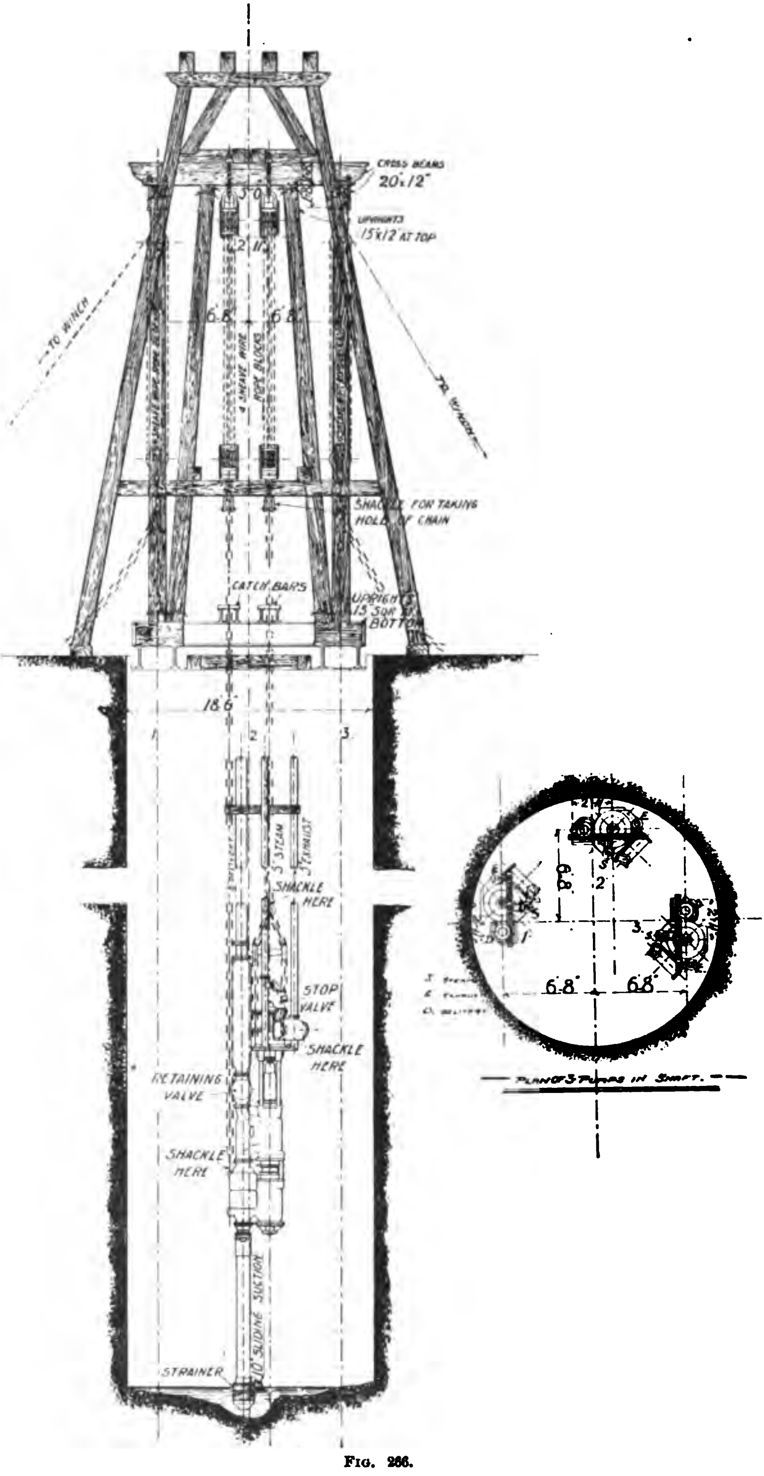
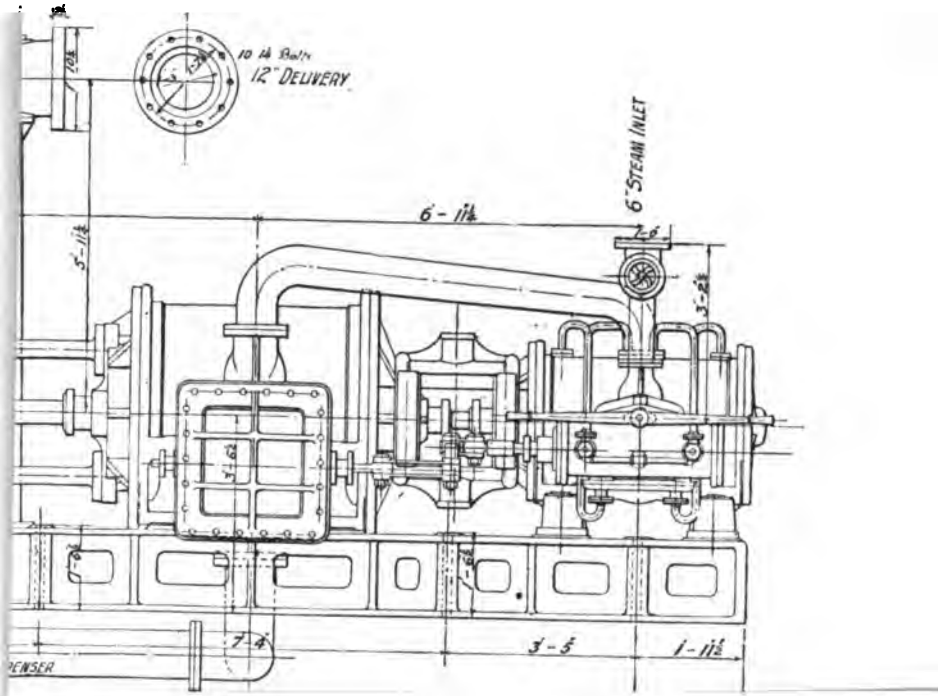


Fig. 266.

Showing Evans' Straight-line Differential Ram Sinking Pump Suspended in Shaft.


10 1¼ Bolts
12" DELIVERY
6" STEAM INLET
6 - 11¼
5'-11½
3'-2½
7-4
3'-5
1-11½
PENSER

required. The pipes are attached as the sinking proceeds; thus in the event of sudden inrush of water, or the pumps being overpowered through any cause, they can be readily drawn up above water level.

For heavy pumps, for depths of more than 300 feet, whether bucket or ram type, Messrs. Evans usually recommend double chains to each pump. Two chains, one on either side, cause the pump to be much steadier, prevent twisting, and keep the pipes more in line. Special stays and clips are usually provided with the pumps and rig-up; these are securely fastened to the chains, but a certain amount of clearance is allowed in all the clips to enable the pipes to expand and contract freely according to their temperature, or to accommodate themselves to any underwise movement.

No hosepipe of any kind, either for steam or water purposes, is recommended by the makers for use in connection with these sinking pumps, nor is the use of such hose necessary. If a reasonable amount of horizontal length of pipe and a few bends are provided at the surface, ample accommodation for all movements is thereby provided for without straining joints or causing other trouble. Flexible hose of any description, either india-rubber, metallic, or composition, is expensive, more or less unreliable, and often introduces a source of great danger. Should one of them burst with high-pressure steam in a confined space serious results may accrue.

Messrs. Evans recommend their Griff pattern bucket sinking pump for all purposes to a depth of about 300 feet, and in larger sizes up to 360 feet, and above this depth their differential ram "straight-line pattern" (*see fig.* 265, *page* 448) shown in section. This latter pattern of pump is made in sizes varying from a capacity of 30 gallons per minute up to 500 gallons per minute; and on emergencies, under favourable conditions, these pumps can be increased in speed to as much as 50 per cent over these quantities. Messrs. Evans have made a great many underground steam pumping engines on their patent Cornish duplex system. Fig. 267 (*see sheet* 9, *between pages* 450 *and* 451) shows a large pumping engine on this system fixed in the Bickershaw Collieries, Wigan. This engine is on the compound condensing principle, and has two 25-inch diameter high-pressure steam cylinders, two 44-inch diameter low-

pressure steam cylinders, four 11½-inch diameter rams coupled in pairs by side rods, all 36-inch stroke. It is supplied by steam from boilers on the surface, at a pressure of about 100 pounds per square inch, through an 8-inch diameter steel main about 600 yards long, and delivers 50,000 to 60,000 gallons of water per hour through a 12-inch diameter steel delivery main about 500 yards long, to a vertical height of about 1100 feet. The condensers are Messrs. Evans' Cornish independent type, each air pump being 12 inches diameter, with its separate steam cylinder 8 inches diameter. Either half of the engine is capable of being worked independently, as also either condenser, or the two sides of the engine may be run together by means of the patent system of connections, so as to give the duplex motion, one half of the engine being kept half a stroke in advance of the other; thus one engine reverses whilst the other half is running at its maximum speed, so preventing shocks and keeping up a steady discharge.

In case of accidents, however, one half may be laid off at a few minutes' notice, and the other continue to work, thus forming its own stand-by. Notwithstanding the length of the steam range, the loss of pressure is merely nominal, from two to three pounds being the greatest difference observed on the gauges. The whole installation has worked smoothly, economically, and satisfactorily since being set to work, and the makers have reason to believe—although no actual test has been made beyond the taking of the rise of temperature in the water—that the working results are most favourable from a steam consumption point of view.

In electrical pumps Messrs. Evans have had considerable experience; during the last few years they have put in a number of important installations, particularly for high lifts, at collieries in various parts of the country.

Representative examples of their electrical vertical and horizontal treble-ram pumps are shown in figs. 268, 269, and 270. (*See pages* 454 *and* 455.)

These pumps are of very strong and substantial construction, with the details carefully worked out, gearing being usually machine-cut and raw hide pinion for the first motion, and double helical for the second motion; crankshafts of steel, cut out of the solid, for the heavier horizontal pumps, with four journals, one to each crank neck.

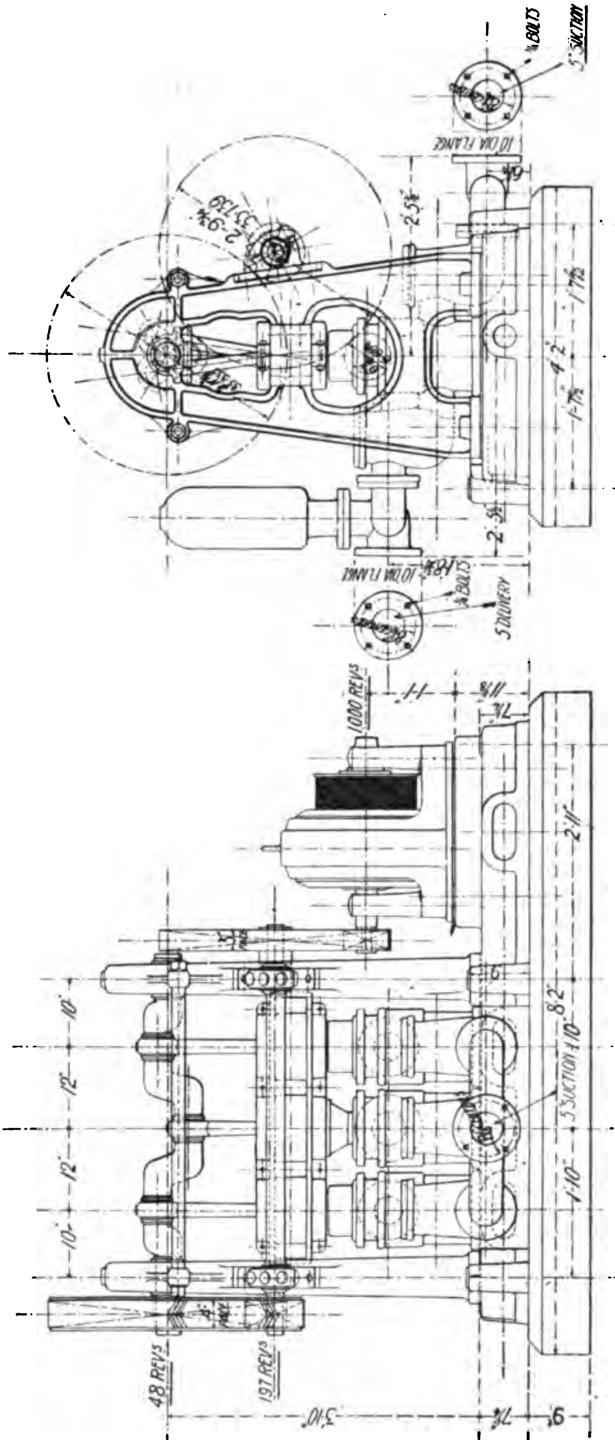


FIG. 268.
SHOWING MESSRS. JOSEPH EVANS & SONS' THREE-THROW VERTICAL ELECTRIC PUMP.

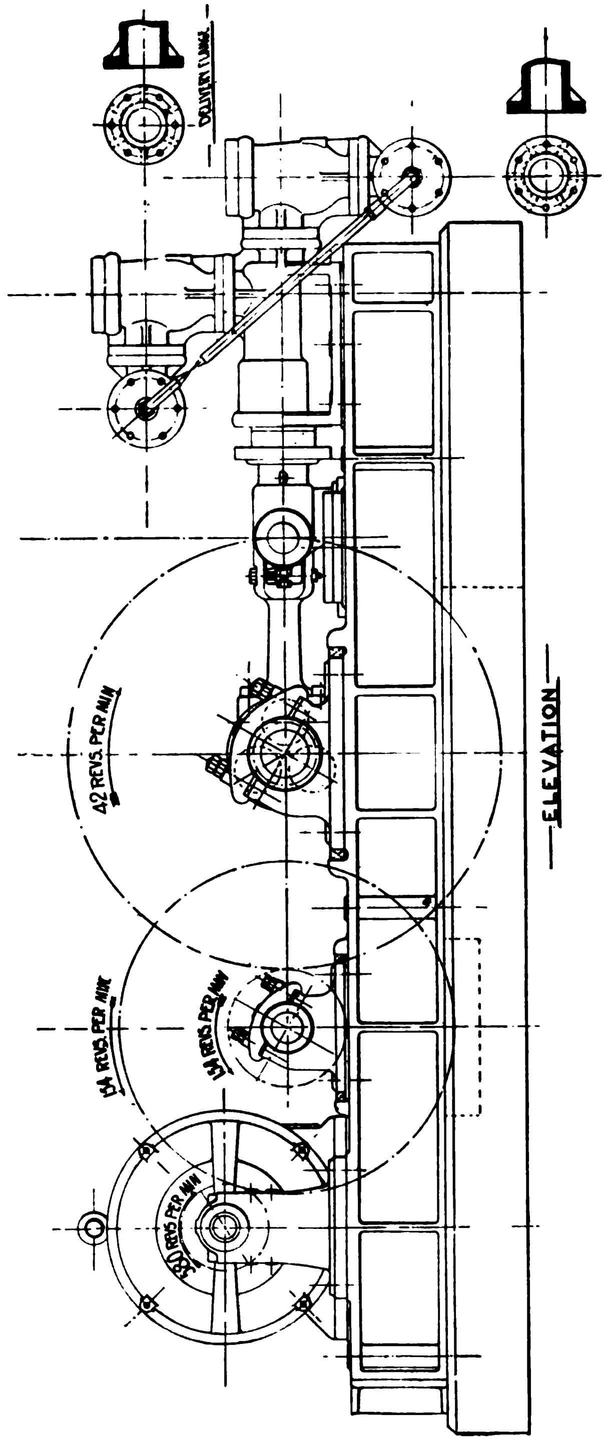
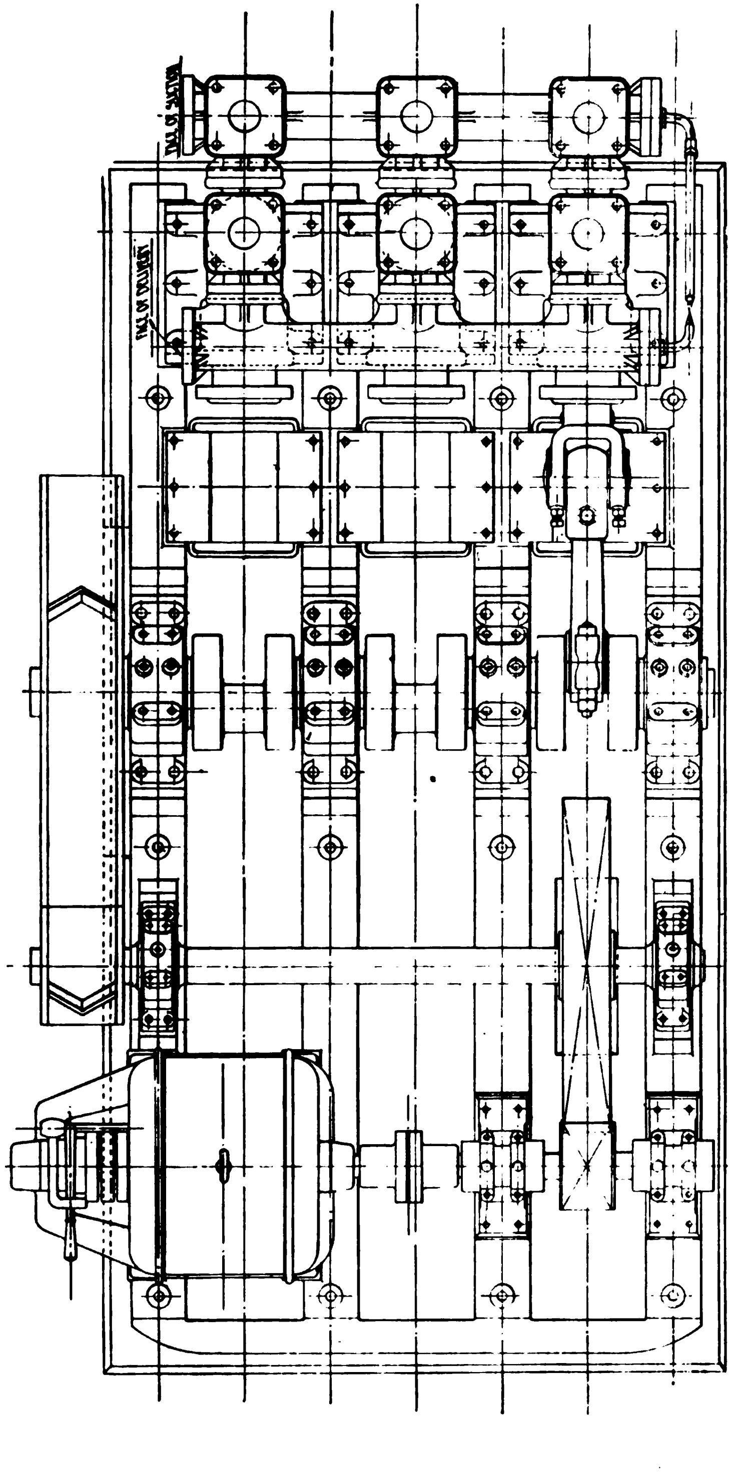


Fig. 269.
Elevation of Messrs. Joseph Evans & Sons' Horizontal Three-Throw Pump, Driven by a Directly-Geared Slip Ring Three-Phase Motor.



— PLAN.—

FIG. 270.—PLAN OF DIRECT-GEARED ELECTRICAL THREE-THROW PUMP, WITH SLIP RING MOTOR.

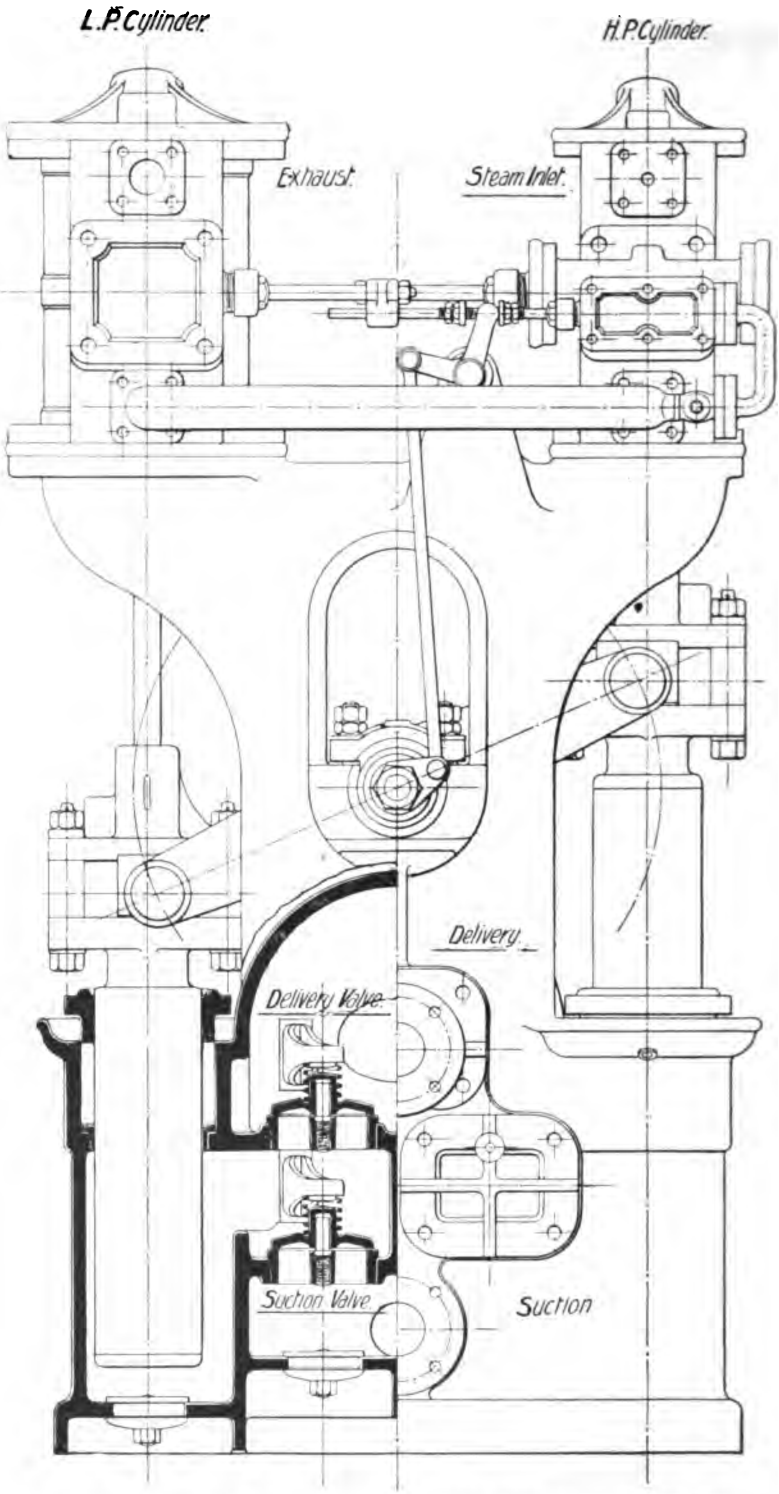


FIG. 271.—MESSRS. J. EVANS & SONS' BEAM COMPOUND HIGH-PRESSURE BOILER FEED PUMP.

The pumps are so designed that the various portions are subdivided into pieces of moderate size and weight, so that in case of a mishap any part can be easily and cheaply renewed, and readily got into position in the mine. Messrs. Evans recommend driving by cotton ropes from the motor in all cases where the power for driving exceeds 60 brake horse power.

One of the horizontal type of pumps was supplied by Messrs. Evans to the Bradford Colliery, Manchester, where it forces up the shaft 1680 feet in one lift. Numerous other examples are forcing various heights, including 1200 feet in one lift at the Windsor Colliery, South Wales, another similar set having been supplied for a similar lift to the Albion Colliery, South Wales. These pumps show an efficiency of from 85 per cent to 90 per cent.

A pump which Messrs. Evans have designed to meet the requirements of the modern high-pressure boilers is their beam compound feed pump, for feeding boilers. This pump is illustrated by fig. 271. It has the special merit of being able to run either as slowly as may be desired, with absolute certainty of turning the centre, or at any speed up to its maximum capacity, by merely adjusting the steam stop valve to suit, no other adjustment being necessary. It is well known that flywheel pattern pumps cannot be run below a certain number of revolutions with a certainty of turning the centre. Furthermore, the beam pump, being compound, is economical in steam, and owing to its design occupies a comparatively small amount of ground space, and gives a long stroke without being unduly tall.

All parts are of very strong and simple construction, and are readily accessible.

Most of the boiler feed pumps hitherto on the market for high-pressure boiler feeding have been fitted with bucket pump ends, and it is well known that any form of bucket or piston necessitating rings or other packing is subject to considerable wear, and that there is always a certain amount of slip and loss going on which may not always be detected. The beam pump, however, having outside-packed rams, any leakage can always be detected, and by screwing up the packing glands, or adding fresh packing, is maintained in an efficient state.

THE PULSOMETER.

At the commencement of this section we referred to that

early type of pump, Savery's "Miner's Friend," and compared it with its modern prototype, which it closely resembles in principle. The Pulsometer, made by the Pulsometer Engineering Company Limited, of Reading, consists of two pear-shaped vessels placed side by side. (*See* **AA**, *fig*. 272.) At the top, where

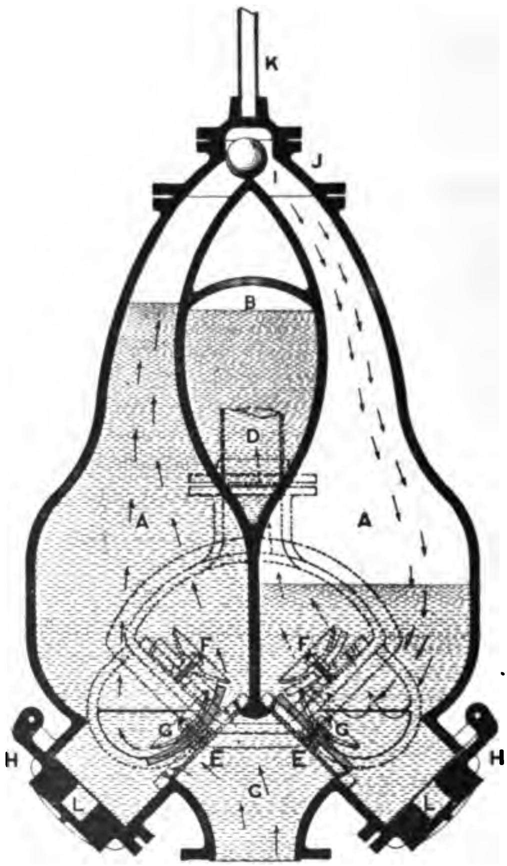


FIG. 272.

SECTION OF THE PULSOMETER.

K The Steam Pipe.
D The Delivery Pipe.
C The Suction Pipe.
E E The Suction Valves.
F F The Delivery Valves.
B The Air Vessel.

the stalks of the pears might be imagined to be, they both connect with the steam pipe, and at this point a ball valve is so contrived that steam admission is always open to one vessel and closed to the other. At the bottom the vessels

connect, through suction valves (**E E**), with a common suction pipe (**C**), and similarly through delivery valves shown in dotted lines at (**F F**), to a common delivery pipe (**D**).

In operation the steam acts directly upon the surface of the water in the following manner: Suppose the position of affairs to be as represented in fig. 272, in which the left side is shown full of water, whilst the right side is open for steam admission from the steam pipe (**K**). The steam pressing upon the surface of the water forces it out through the delivery valve (**F**) until the level of the water is so low that steam begins to escape

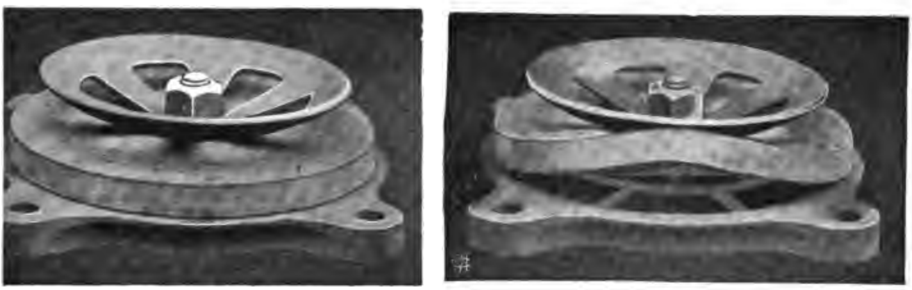


FIG. 273.
PULSOMETER VALVES.—THE VALVE IS A DISC OF INDIARUBBER RESTING ON A GRID.

through the delivery valve and passage also. The moment this takes place there is naturally a violent agitation of the water, the effect of which is to condense the steam filling the vessel and to form a vacuum. Until this point has been reached the surface of the water has been quiescent, and although the first contact of the steam means a certain amount of condensation, a film of hot water is immediately formed which prevents further condensation until the vessel is emptied of water.

The sudden condensation of the vessel full of steam, and the vacuum produced, causes the steam or air above the water on the left side to push the ball over in its effort to expand into the right-side vessel; this immediately admits steam to the left-side vessel, and the water is similarly forced out. In the meantime the vacuum in the other vessel has permitted the atmospheric pressure to force water up the suction pipe, through the suction valve, and into the pump chamber; this process is repeated alternatively in the two vessels. The space between the two chambers (**B**) is utilised as an air vessel. The

Fig. 274.
Showing method of Slinging a Pulsometer in a Sinking-Pit.

valves are of the grid type—that is, metallic grids with rubber discs as valves. (*See fig.* 273, *page* 459.)

The pulsometer pump is perhaps not an appliance one would care to put down as a permanent pumping engine; the consumption of steam is high, and the vertical height to which it will deliver water is limited; still it is a pumping appliance which, for certain purposes, gives excellent results, and it possesses features which entitle it to a prominent place in a work of this character.

Its advantages are these: It is simple in construction, and not easily put out of order; there are no working parts, except the valves, and consequently for dealing with dirty and gritty water it may be adopted without hesitation—in fact, the makers claim that it is well adapted for pumping sludge, sand, water from coal washers, and any water containing a large amount of solid or gritty matter; it is light, and occupies small space for the volume of water dealt with, and can therefore be readily used as a slung pump in shaft sinking, a purpose to which it has been often put.

They are constructed to raise water to a height of 80 to 90 feet—greater height would necessitate their being arranged in series at different levels. It will, of course, be apparent that the pulsometer consumes its own exhaust steam. To deal with about 200 gallons per minute the pulsometer, size 6, measures 25 inches × 24 inches × 42 inches high.

In sinking the shafts at the Maypole Colliery, near Wigan, which had to pass through heavily-watered strata, Mr. James Keen—to whose determination and indomitable energy the success of this undertaking was largely due—adopted pulsometer pumps, and he spoke very highly of their performances.

The arrangement was similar to that shown in fig. 274, a pair of pulsometers, with a combined capacity of 160,000 gallons of water per hour, being suspended at each of three points in the shaft, raising, in series, this immense volume of water.

HIGH-LIFT TURBINE OR CENTRIFUGAL PUMPS.

Some years ago, Messrs. Mather & Platt, of Salford—a name which has long been familiar in mining in connection with deep boring appliances—turned their attention to the centrifugal pump.

Like a centrifugal fan, the centrifugal pump consists of an arrangement of revolving blades working in a casing. The inlet is at the centre, the outlet a point in the circumference of the casing.

For large volumes of water, and a low lift, the centrifugal pump offers many advantages, and the efficiency is fairly high. Messrs. Mather & Platt sought to apply the principle to high lifts, and their high-lift turbine pump is perhaps one of the most remarkable examples of modern pumping appliances. A simple revolving apparatus, which—with neither valves, pistons, nor other wearing parts, beyond the bearings, and only occupying a space of 15 feet 6 inches × 4 feet 11 inches × 5 feet 5 inches,

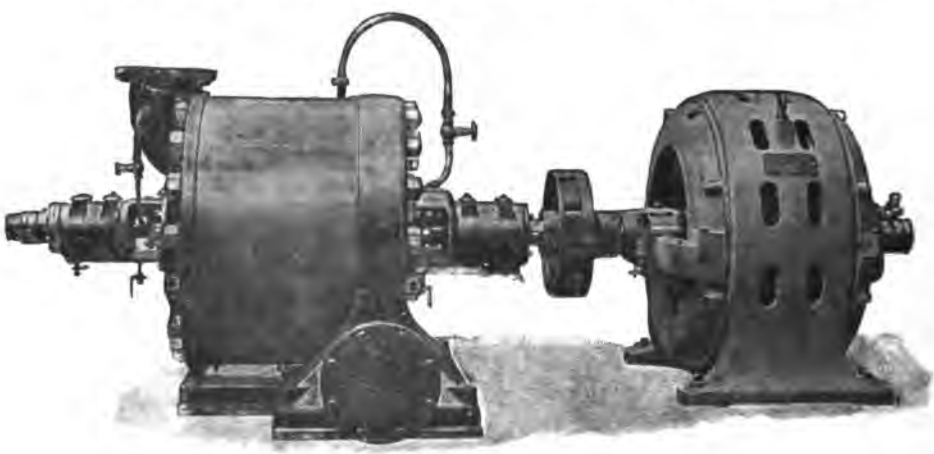


FIG. 275.

MATHER & PLATT'S HIGH-LIFT CENTRIFUGAL PUMP.

inclusive of the motor—can deliver 1000 gallons per minute to a vertical height of 320 feet, with a guaranteed efficiency of 75 per cent, is one likely to prove of immense value in colliery pumping, especially where electric power is available. The figures quoted refer to the pump shown in fig. 275, which is one of several in use at the De Beers Mines, Kimberley. The motor is a 160 brake horse power induction type, which, at 735 revolutions per minute, develops 130 brake horse power, and at this speed the pump delivers 1000 gallons per minute to a total height of 320 feet, showing an overall efficiency of 75 per cent.

Where electric power is available this type of pump would

appear to be eminently suited for sinking purposes. In this case the axis of revolution would be vertical with the motor enclosed in a water-tight casing at the top. The whole could be slung in the shaft in the usual way, and the absence of reciprocating motion would considerably reduce the difficulty of suspension and support. (*See fig.* 276.)

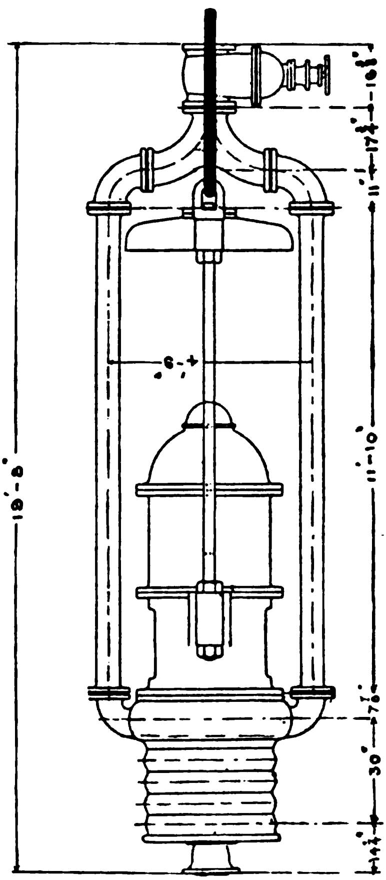


FIG. 276.
A HIGH-LIFT CENTRIFUGAL OR TURBINE PUMP, ARRANGED AS A SINKING PUMP, TO BE SLUNG IN THE SHAFT.

A number of these pumps have been sent to a mine in India, where they are set to work in the manner shown in

fig. 277. At each of the three levels two pumps are fixed, making six in all, pumping in series to a total height of 1650 feet.

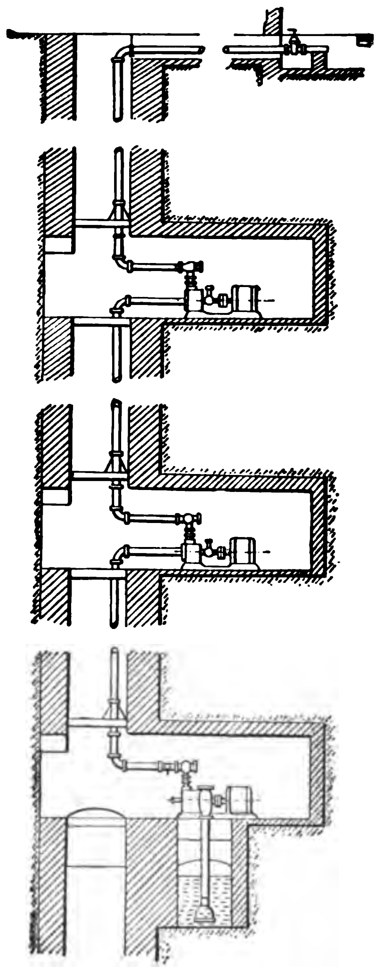


FIG. 277.
SHOWING HIGH-LIFT CENTRIFUGAL PUMPS, COUPLED IN SERIES.

THE RIEDLER PUMP.

In spite of the advantages possessed by a flywheel in connection with reciprocating mechanism, we have elsewhere given our reasons for expressing the opinion that it is scarcely adapted for pumping engines, for the same reason that makes it so desirable an appliance in connection with many other

types of engines—its effect in reversing the motion of the reciprocating parts without a pause. In driving a dynamo, for example, this steady speed is most important, and there must

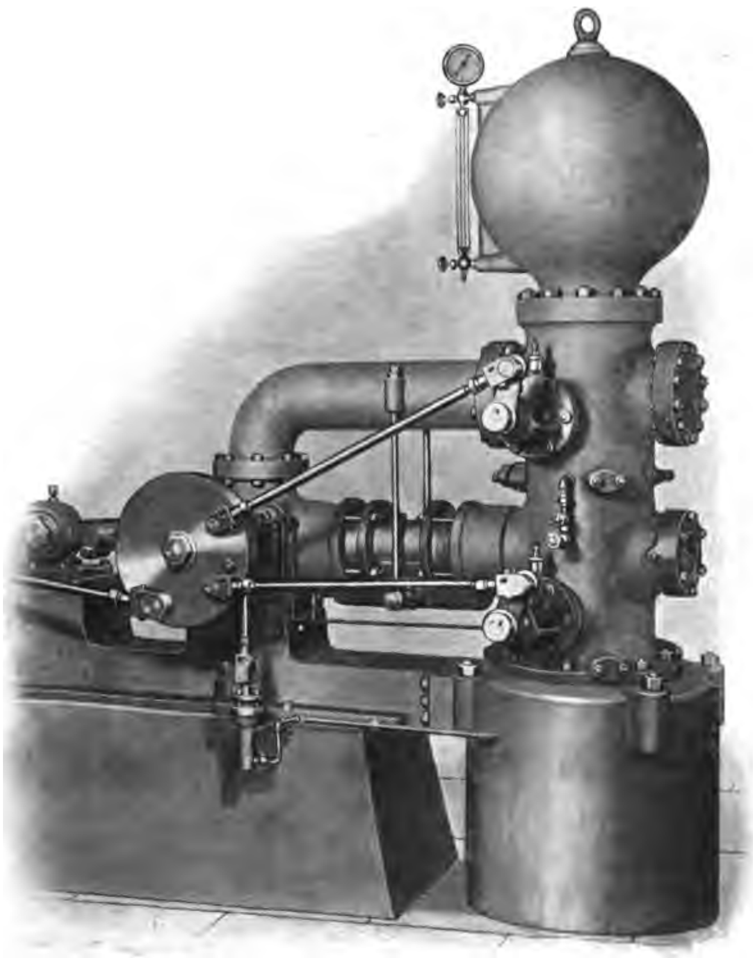


FIG. 278.
SHOWING THE VALVE-OPERATING MECHANISM OF A RIEDLER PUMP.

not be any pause at the end of the stroke. The flywheel prevents that pause, and tends to maintain a constant speed.

In the ordinary type of pump, with the ordinary type of

valve opened and closed by the water, not only must the speed of the pump be restricted to 100 to 150 feet per minute, there

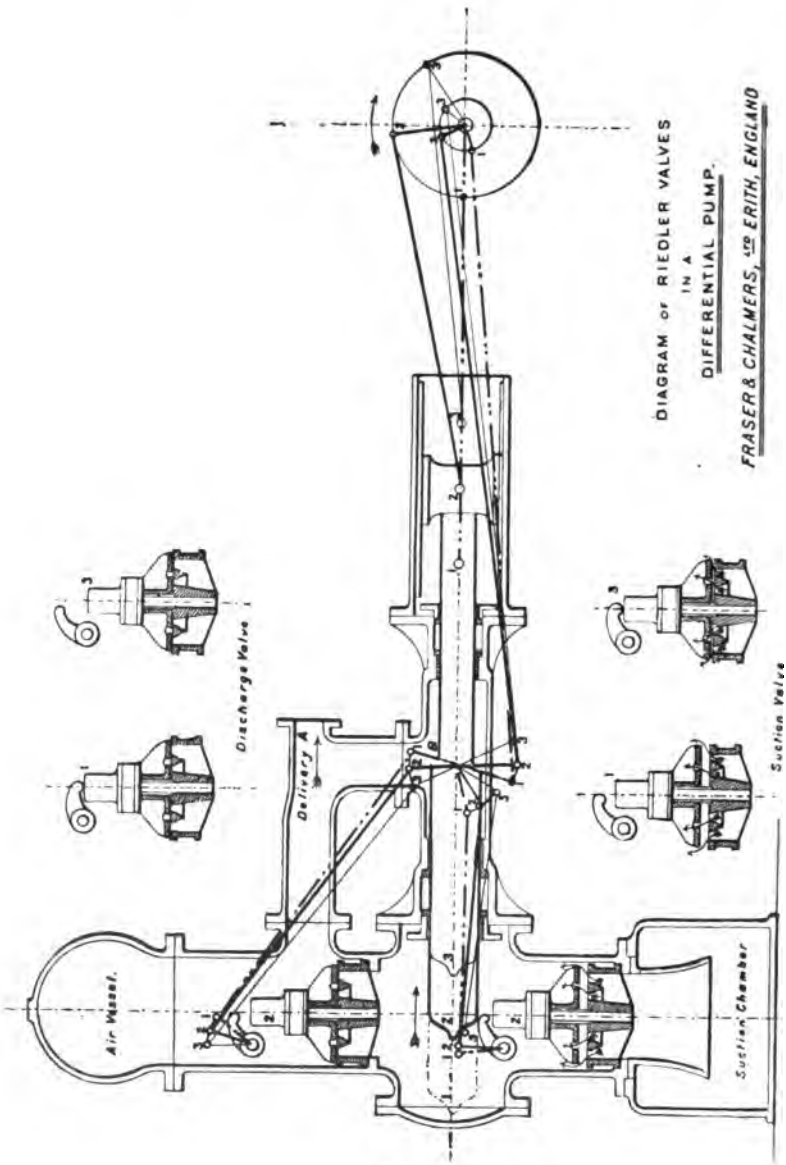


FIG. 279.

FIG. 279.

must also be a brief pause to enable the open valves to close before the reversal of motion commences.

In the Riedler type of pump, however, this difficulty disappears, and we may adopt the flywheel; indeed, we should prefer to do so, and the pump may safely work at a higher speed. This is effected by the introduction of mechanically operated positively closed valves, which are pressed down upon their seats at the precise moment that the pump reaches the end of the stroke, and held down until the time arrives for the valve to open, when the lever or finger (fig. 279) rises, leaving the valve free to open under the influence of the water.

Fig. 279 illustrates the action of this type of pump very clearly. Two separate sections of the delivery valve are shown; in the one on the left the finger is holding the valve down, on the right the finger is raised, leaving the valve free to open. All pounding of the valves upon their seats is avoided, and slip is reduced to a minimum. The Riedler pump is therefore capable of working at a higher speed than other reciprocating pumps, and admits of a crank or flywheel motion. It is singularly well adapted for the application of electric motive power, doing away with a considerable amount of the heavy gearing necessary with a three-throw pump. As a matter of fact a single Riedler pump of a given diameter is equal in capacity, at its normal speed, to a set of three-throw pumps of the same size. Fig. 280 (*see page* 468) shows this type of pump with single reduction gear and electric motor.

The valves have a lift of from one to two inches, and present a large area of water passage when open, so as to reduce the velocity of the water passing through the valve.

In ordinary pumps—direct-acting and three-throw, for example—there are usually several small valves for suction and delivery, with springs to close them quickly. The lift of the valve is small, and the several water passages small, giving a high velocity.

Fig. 279 shows the Riedler differential pump in diagram to illustrate the action of the valve and valve gear. It will be observed that the plunger is shown in thick lines, also in two other positions by thin lines and dotted lines. The three positions are numbered 1, 2, and 3, and the several moving parts of the pump are similarly numbered, as well as the separate

sections of the delivery and suction valve. These figures indicate the relative positions of the several parts at a given moment. For instance, the thick-lined plunger is position 2;

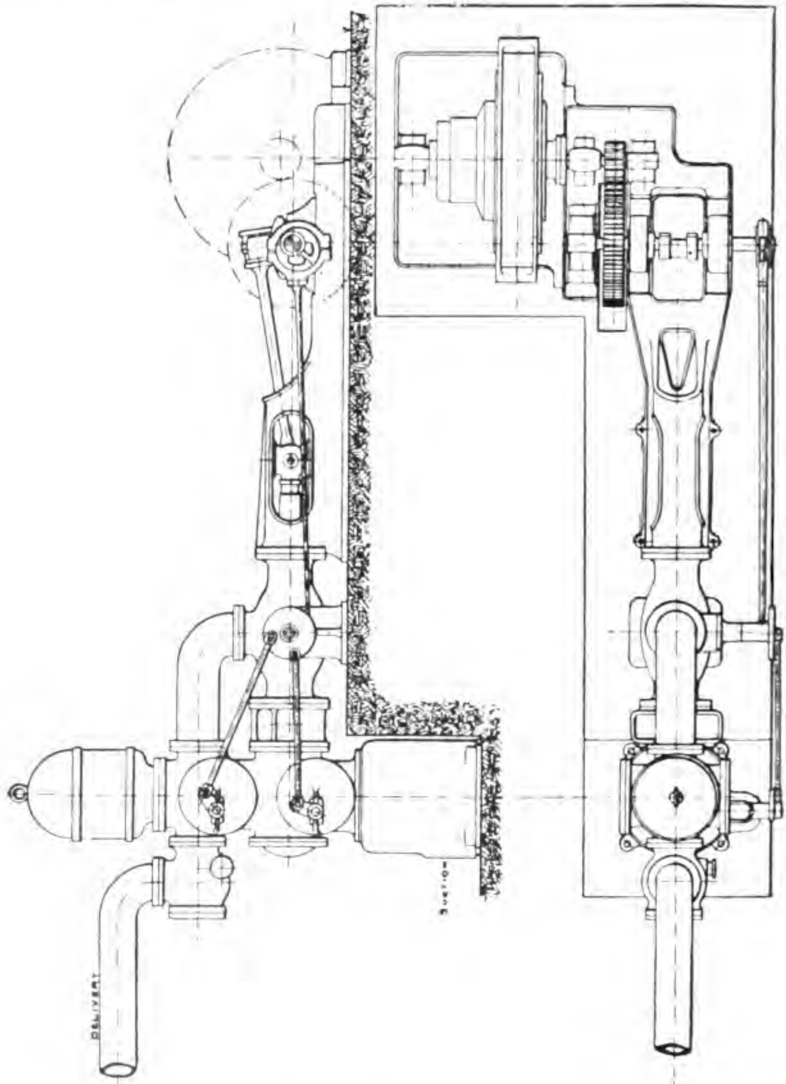


Fig. 280.
Showing a Riedler Differential Pump Coupled to an Electric Motor, with Single Reduction Gear.

the delivery valve is closed, but the finger is lifting so as to leave the valve free to open when the stroke is reversed; the suction valve is open, but the finger has commenced to move

down, so that when the plunger approaches the end of the suction stroke the valve will be in the position 3, almost closed.

The Riedler differential pump is to all intents and purposes a double-acting ram pump, with *only one suction valve and only one delivery valve.*

The ram or rams are of different diameters, one having exactly twice the area of the other. As the pump makes a stroke to the left, the large ram discharges the water through the delivery valve, and one half of the volume flows into the barrel B, the other half passing into the delivery pipe. On the reverse stroke the water in the barrel B is discharged through the delivery pipe.

Fig. 281.
Showing the various parts of the Riedler Valve.

The Riedler pump possesses the following advantages:—It can work at a much higher speed than ordinary reciprocating pumps, and that without the slightest shock or pounding of the valves; the flow of water is indeed continuous, not a series of movements alternating with pauses—a small and less costly pump, in a smaller chamber, and a less costly foundation, will therefore do the work of a larger pump; the slip is reduced to a minimum, not merely increasing the efficiency of the pump but also prolonging its life. Figs. 281 and 282 (*see page* 470) show the Riedler pump valve; the former shows the several parts, the latter shows the complete valve.

The following examples of sizes and capacity, speed, etc., refer to the type of pump adapted for electrical driving, as illustrated in figs. 278 and 280 (*see pages* 465 *and* 468), namely: for 400 gallons per minute, to a height of 300 yards, the rams would be $7\frac{1}{2}$ and 5 inches diameter respectively, by 2-foot stroke, and would work at 120 revolutions per minute, or a pump speed of 480 feet per minute; for 700 gallons per minute, to a height of 500 yards, the rams would be $9\frac{1}{2}$ and $6\frac{3}{4}$ inches diameter, 3-foot stroke, and 80 revolutions per minute, giving the same pump speed of 480 feet per minute.

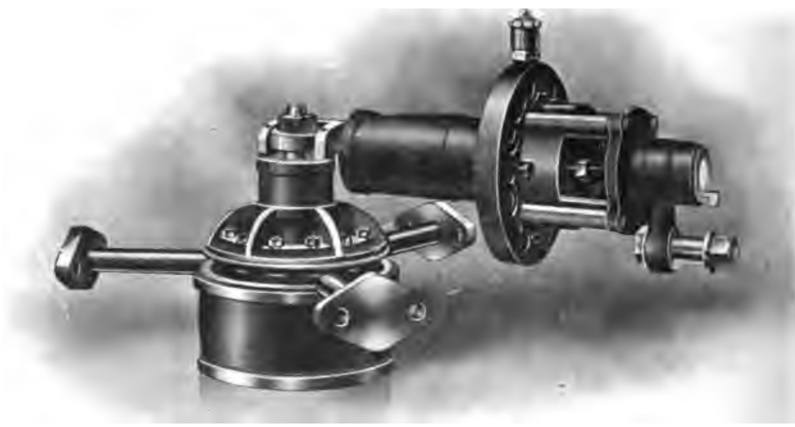


FIG. 282.
THE RIEDLER VALVE.

One of the largest Riedler pumps which Messrs. Fraser & Chalmers have installed in Great Britain is at the collieries of the Powell Duffryn Steam Coal Company. The writer has not had the privilege of visiting the Powell Duffryn Collieries, but, in common with others who read mining literature, he has been impressed with the fact that the management of this concern believes in good modern mechanical equipment, and is apparently determined to have the best. The largest installation of the Riedler pump is to be found there. The largest air compressor (also of the Riedler type) is in operation at the same place, and the writer believes that a large installa-

tion of three-phase electric power plant is contemplated in connection with the Powell Duffryn collieries.

The Powell Duffryn pumping engine is illustrated in figs. 283, 284, and 285 (*see sheet* 10, *between pages* 470 *and* 471), which, together with a large amount of useful information and other illustrations for the purposes of this book, have been kindly placed at our disposal by Messrs. Fraser & Chalmers, of Erith, Kent. The information relates not only to pumping, but to other operations referred to elsewhere, and has an especial value in the fact that it relates to actual installations of machinery and appliances at large modern British collieries.

The large pumping engine illustrated in figs. 283, 284, and 285 was built for the Powell Duffryn Steam Coal Company, in June 1897. The engine is a cross compound condensing engine, 36 inches and 57 inches × 48-inch stroke, with a double-acting Riedler pump behind each cylinder; the plungers are $6\frac{7}{8}$ inches diameter. The capacity of this pump is 1000 gallons per minute to a head of 1600 feet when running 40 revolutions per minute, equal to 320 piston feet per minute. When desired, either side is capable of being disconnected, and the full duty can be done by remaining side, running at 80 revolutions per minute, equal to 640 piston feet per minute.

The cylinders are steam-jacketed, with valve chambers cast in the body of the cylinder. The valves are single-ported in the high-pressure and double-ported in the low-pressure cylinder. The inlet valves are closed by spring dashpots, the point of cut-off is controlled by governor on the high-pressure side, by hand adjustment on the low-pressure side, or by governor when running that side alone.

Both high and low-pressure pistons are fitted with two rings and a lining of special piston babbitt. A reheater receiver is mounted overhead and fitted with $3\frac{1}{2}$-inch wrought-iron tubes, steam passing through the tubes.

A special feature in this pump is that all pipes are kept above the floor. On account of the bad nature of the ground, a substantial framework was built of I beams and channels set on walls to carry the engine. The governor is of the Porter type, having adjustable weight so that the engine can be controlled at any desired speed.

The pump barrels are of cast steel, suction and delivery valves and seats in each are of gun-metal, with an area of 58 square inches for the passage of water. The valves are cone-seated, and are fitted with leather sealing ring; the delivery air vessels are of steel.

The low-lift pumps at the back of the main pumps act also as air pumps, and deliver the water to a tank at the back of the engine room, and from here the water is delivered to the main pump. This avoids any chance of the main pumps drawing air, which might be dangerous under a high head. These air or low-lift pumps are single-acting, with 13-inch diameter plungers with gun-metal valve plates and special Kinghorn type of valves. The jet condensers are at the side of these air pumps, with the exhaust pipe leading into the top. The amount of water drawn through the condensers and air pumps is controlled by a float in the tank at the back.

The flywheel is 16 feet diameter, weighing about 16 tons. A two-stage air compressor is supplied to charge air vessels, and, in addition to these, an independent one, steam-driven, so that the air vessels may be charged when the air vessels are standing.

Applying, as a further example, the rule previously given: $6\frac{7}{8} \times 6\frac{7}{8} \times \cdot 034 \times 320$ equals, say, 514 gallons per minute each pump, or together 1028, when running at the normal speed of 40 revolutions per minute. The loss due to slip is considerably less than would be the case with ordinary valves, so that we may take it the figure given as the normal capacity of this pumping engine, 1000 gallons per minute, is correct.

Compare the capacity of this pump with the duplex pumps already referred to, with rams three times the area.

THE GUTERMUTH PATENT VALVE.

A remarkable development in pump valves has been adopted by the same firm (Messrs. Fraser & Chalmers) and applied both to pumps and compressors. The Gutermuth valve consists of a plate or strip of metal coiled upon a spindle in the manner suggested in figs. 286 and 287. It is claimed that these valves are simple and cheap, light and noiseless in action, work at high speeds and under fairly high pressures.

Their application is responsible for the pump shown in

fig. 288 (*see page* 474), which has a spherical body with the valves all inside the pump. The water passages, suction and delivery

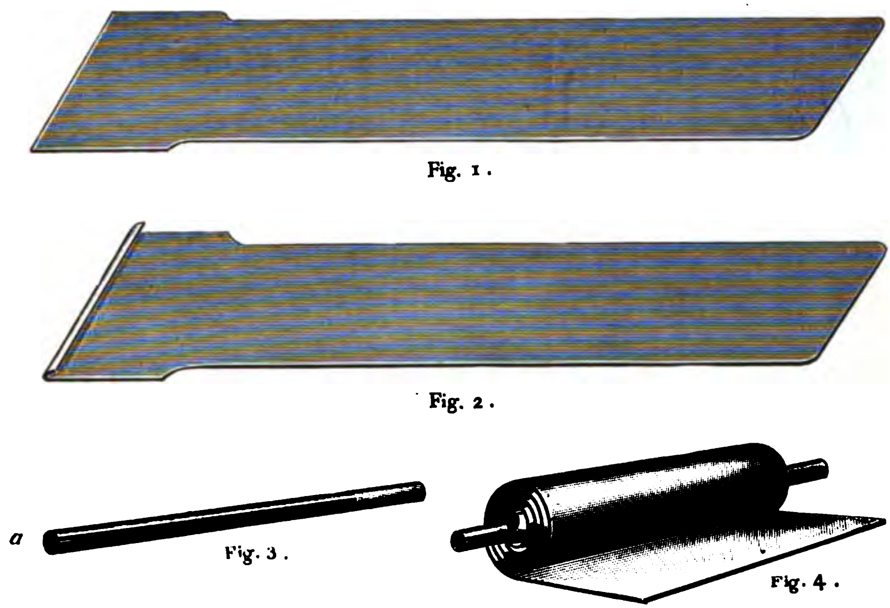


FIG. 286.

ILLUSTRATING THE PROCESS OF CONSTRUCTION OF THE GUTERMUTH VALVE.

valves, all form part of one arrangement which can readily be withdrawn at the side and replaced with a spare set, the whole operation being completed in a very short space of time.

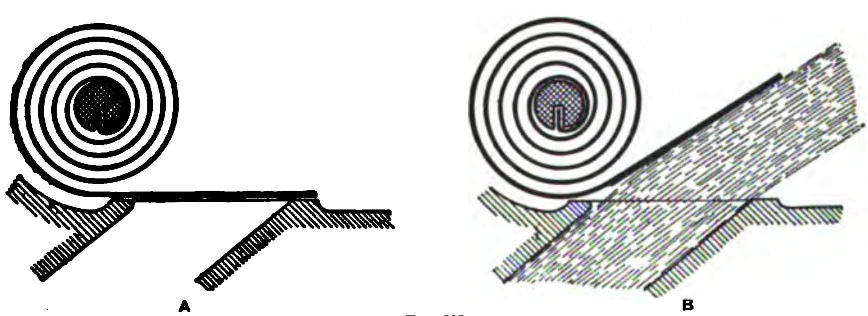


FIG. 287.

THE GUTERMUTH VALVE.—A, CLOSED; B, OPEN.

The impression one receives from the illustrations, and from an inspection of the valves themselves, an opportunity the writer

had some little time ago, is that they are too light and delicate for hard work. The fact, however, that a firm of the experience

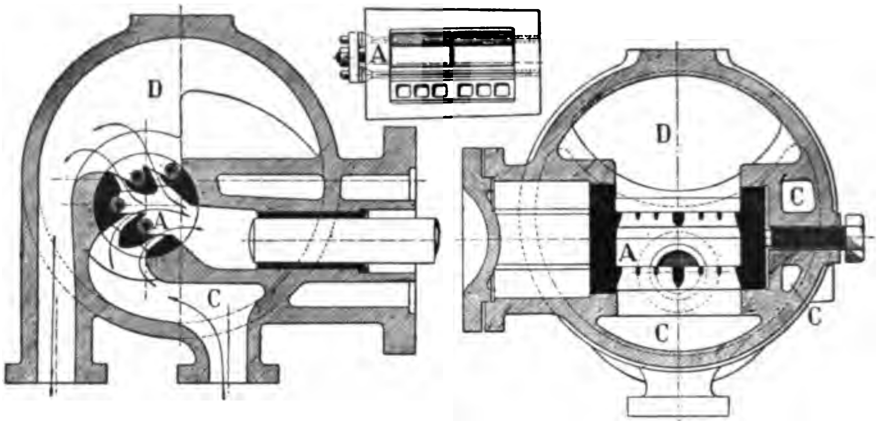


FIG. 238.
MESSRS. FRASER & CHALMERS' GUTERMUTH PUMP.

of Messrs. Fraser & Chalmers have adopted the Gutermuth valve must operate in its favour, as indicating their confidence in the valve as a practicable appliance.

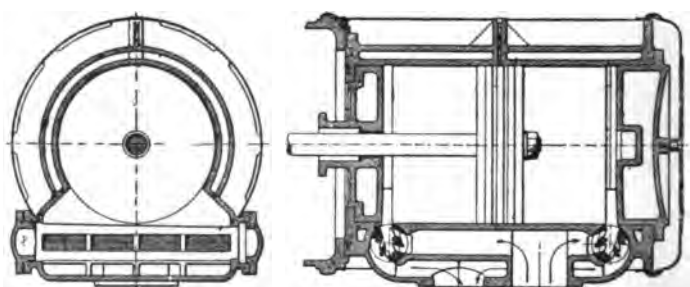


FIG. 239.
THE GUTERMUTH VALVE APPLIED TO AN AIR COMPRESSOR.

CALCULATIONS RELATING TO PUMPS.

We have already given one or two examples of calculations as to the capacity of pumps; a few additional examples and rules no doubt will be useful.

To calculate the size of a pump to deal with a given quantity of water: In estimating the capacity of pumping plant for mining purposes, we advocate the plan of providing a

pumping plant capable of dealing with the water made in twenty-four hours with twelve hours' pumping, so that if the feeder of water was equal to 100 gallons per minute, a pump of 200 gallons per minute capacity would not be out of place.

Suppose we take this figure as the basis of the present example. Required the size of a duplex double-acting ram pumping engine to deliver 200 gallons per minute to a height of 300 yards, with steam at the pump at 60 pounds per square inch.

Assume a pump speed of 100 feet per minute. Divide the gallons per minute by the speed multiplied by ·034 and take the square root of the result. As the pump is to be a duplex we divide the total quantity equally between the two double-acting rams, adding 5 per cent for slip:—

$\sqrt{\frac{105}{100 \times \cdot 034}} = \sqrt{\frac{105}{3 \cdot 4}} = \sqrt{30 \cdot 88}$ = say $5\frac{3}{4}$ inches diameter of each ram.

To find the total pressure on the ram: $5 \cdot 75^2 \times 900 \times \cdot 34 =$ 10,117·125 pounds. To allow for friction of water in the pipes and the friction of the pump, add 50 per cent, giving a total of 15,175·6875 pounds. Divide by the steam pressure, 60, which gives 253 square inches area of each piston, equals, say, 18 inches diameter. The stroke would be about 18 inches.

Speed of Pumps: By the term speed of pumps we mean the actual distance which the ram or plunger travels in a minute. In underground pumping engines the stroke is comparatively short, and the speed slow, on account of the large number of reversals of motion per minute. Generally, the shorter the stroke the slower the speed. Of course this does not apply to special types of pumps like the Riedler.

A fair speed with short-stroke pumps is from 50 to 100 feet per minute. We may again quote a rule which already has been used elsewhere: Take the square root of the stroke in feet and multiply by 80.

Examples: A pump with 12-inch stroke: $\sqrt{1} = 1$ and 1 multiplied by $80 = 80$ feet per minute.

A longer stroke will admit of a higher speed; thus, 2 feet stroke: $\sqrt{2} = 1 \cdot 414$, and multiplied by 80, equals, say, 113 feet per minute. Similarly, 18-inch stroke: $\sqrt{1 \cdot 5} = 1 \cdot 225$, and multiplied by $80 = 98$, say 100 feet per minute.

Example: Three-throw pump, single-acting rams, for 300 gallons per minute.

Pump speed, say, 100 feet per minute, but the pumps are single-acting, and therefore only deliver water for 50 feet of pump travel per minute: $300 \div 3 = 100$ gallons per minute each ram; add 5 per cent, equals 105: $\sqrt{\frac{105}{50 \times \cdot 034}} = \sqrt{61 \cdot 76}$, say $7\frac{7}{8}$ inches diameter and 18-inch stroke.

CAST-IRON PIPES FOR PUMPING.

Cast-iron pipes are generally used for permanent pumping plants. For slung pumps, in sinking, steel pipes are more suitable, as being very much lighter and stronger in proportion. Steel pipes, however, are not always suitable for permanent plant, being much more readily acted upon and corroded by mine water.

The cast-iron pipes are made in standard sizes, and are usually 9 feet long. The joints are made tight by means of indiarubber rings, lead rings, corrugated metal rings, and in other ways.

In calculating the weight of cast-iron pipes we can simplify matters if we remember that a cylinder of cast iron 1 inch diameter and 1 foot long weighs 2·45 pounds, and also that for each joint we must allow 1 foot of pipe as the approximate equivalent weight.

Rule: Deduct the square of the inside diameter in inches from the square of the outside diameter in inches, multiply by ·7854, which gives the sectional area of the metal in square inches, and multiply by 2·45 for the weight in pounds per foot.

THE STRENGTH OF CAST-IRON PIPES.

In calculating the strength of cast-iron pipes, and the working pressures which such pipes will safely withstand, it must be remembered that we have two circumstances to take into account, which demand that a liberal allowance or factor of safety should be provided for; these circumstances are irregularities in the pipes, which are likely to exist to some extent in the most carefully-made pipes, and shocks or sudden variations of pressure in the pipes.

Taking the average tenacity of cast iron at 18,500 pounds

per square inch, and the factor of safety 10, we get 1850 pounds per square inch as the safe working pressure in pounds per square inch.

To find the safe maximum pressure at which a cast-iron pipe of a given size and thickness can safely be worked, therefore, multiply twice the thickness of the pipe in inches by 1850, and divide by the diameter in inches; thus, a pipe 6 inches diameter, metal $\frac{1}{2}$ inch thick: 1850 multiplied by 1 and divided by 6 equals 308 pounds per square inch. A pipe 12 inches diameter, metal 1 inch thick: 1850 multiplied by 2 and divided by 12 equals 308 pounds per square inch.

To find the thickness of metal in a pipe of given diameter to safely withstand a given working pressure, multiply the diameter in inches by the pressure in pounds per square inch, divide by 1850 and again by 2.

What thickness of metal in a pipe 12 inches diameter would be suitable for a vertical head of 700 feet?

$$\frac{700 \times \cdot433 \times 12}{1850 \times 2} = \cdot98, \text{ say 1 inch thick.}$$

Steel pipes are about six times as strong as cast-iron pipes; that is to say, a steel pipe of a given diameter and thickness can be used for six times the pressure that would be considered safe for a cast-iron pipe of the same size and thickness.

The following particulars relating to cast-iron pipes may be useful as showing the minimum thickness of metal in pipes of different sizes, as well as the usual range of thicknesses :—

Diameter of Pipe in inches.	Thickness of Metal.	Diameter of Pipe in inches.	Thickness of Metal.
3	$\frac{3}{8}$ to $\frac{5}{8}$	9	$\frac{5}{8}$ to $\frac{3}{4}$
4	$\frac{3}{8}$ „ $\frac{3}{4}$	10	$\frac{5}{8}$ „ $\frac{7}{8}$
5	$\frac{7}{16}$ „ $\frac{3}{4}$	12	$\frac{5}{8}$ „ 1
6	$\frac{1}{2}$ „ $\frac{3}{4}$	15	$\frac{3}{4}$ „ 1
7	$\frac{1}{2}$ „ $\frac{3}{4}$	18	$\frac{3}{4}$ „ 1
8	$\frac{5}{8}$ „ $\frac{3}{4}$	24	$\frac{3}{4}$ „ 1

TABLE SHOWING THE FRICTION OF WATER IN PIPES, EXPRESSED IN FEET-HEAD OF WATER PER YARD OF PIPE.

Diameter of pipe in inches.

Galls. per min.	2½	3	3½	4	5	6	7	8	9	10	12	14	16	18
5	·001													
10	·004	·00 2												
15	·009	·004	·002											
20	·016	·006	·003	·002										
30	·037	·015	·007	·003	·001									
40	·067	·027	·012	·006	·002									
50	·105	·042	·019	·010	·003	·001								
60	·151	·060	·028	·014	·004	·002								
70	·206	·083	·038	·019	·006	·002	·001							
80	·269	·108	·050	·025	·008	·003	·002							
90	·341	·137	·063	·032	·010	·004	·002	·001						
100	·421	·169	·078	·040	·013	·005	·002	·001						
120	·606	·243	·112	·057	·018	·007	·003	·002	·001					
140	·825	·332	·153	·078	·025	·010	·004	·002	·001					
160	1·07	·433	·200	·102	·033	·013	·006	·003	·002	·001				
180	1·36	·549	·252	·131	·042	·017	·008	·004	·002	·001				
200	1·68	·677	·313	·160	·052	·021	·009	·005	·002	·002				
250	2·63	1·05	·489	·251	·082	·033	·015	·007	·004	·003	·001			
300	3·79	1·52	·705	·361	·118	·047	·022	·011	·006	·004	·001			
350	..	2·07	·960	·492	·161	·065	·030	015	·008	·005	·002			
400	..	2·71	1·25	·643	·210	·084	·039	·020	·011	·006	·002	·001		
450	..	3·43	1·58	·813	·266	·107	·049	·025	·014	·008	·003	·002		
500	..	..	1·95	1·00	·329	·132	·061	·031	·017	·010	·004	·002	·001	
600	..	..	2·82	1·44	·474	·190	·088	·045	·025	·014	·005	·002	·002	
700	..	..	3·83	1·96	·645	·259	·120	·061	·034	·020	·008	·003	·002	·001
800	..	..	..	2·57	·842	·338	·156	·080	·044	·026	·010	·004	·002	·001
900	..	..		3·25	1·06	·428	·198	·101	·056	·033	·013	·006	·003	·002
1000	..	..	..	..	1·31	·529	·244	·125	·069	·041	·016	·007	·004	·002
1250	..	..	..	..	2·06	·827	·382	·196	·109	·064	·026	·012	·006	·003
1500	..		..	..	2·96	1·19	·551	·282	·156	·092	·037	·017	·009	·005
1750	..	..	..	..	..	1·62	·750	·384	·213	·126	·050	·023	·012	·006
2000	..	..	..	..	..	2·11	·97	·50	·27	·164	·066	·030	·015	·008
2500	..	..	..	..	..	3·30	1·53	·785	·435	·257	·103	·047	·024	·013
3000	..	..	..	..	..	..	2·20	1·13	·62	·370	·148	·068	·035	·019
3500	..	..	..	..		..	3·00	1·53	·853	·504	·202	·093	·048	·026
4000	..	..	..	..	..	..	..	2·00	1·11	·658	·264	·122	·062	·034
5000	..	..	..	..	..	..	..	3·14	1·74	1·02	·413	·191	·098	·054
6000	..	..	..	..	..	..	..	..	2·50	1·48	·595	·275	·141	·078
7000	..	..	..	..	..	..	..	..	3·41	2·01	·810	·374	·192	·107
8000	..	..	..	..	..	..	..	..	..	2·63	1·05	·489	·251	·139
9000	..	..	..	..	..	..	..	..	..	3·33	1·33	·619	·317	·176
10000	..	..	..	..	..	..	..	..	..	..	1·65	·765	·392	·217

By means of the above table we can ascertain the extra head of water due to the friction of the water in the pipes. For example, suppose we are pumping 3500 gallons per minute through a 7-inch pipe 100 yards long, the extra work to be accomplished to overcome the friction of the water in the pipes would be equivalent to raising the water 100 yards vertically, in addition to the height to which it has actually to

be raised. As a rule the pipes should be large enough to give a velocity not exceeding 200 feet per minute as a maximum.

SIZES OF PIPES SUITED FOR VARIOUS QUANTITIES OF WATER.

Although smaller pipes are often used, the following table gives the sizes of pipes suited for various quantities of water, so as to avoid excessive friction :—

Gallons per minute.	Diameter of Pipe in inches.	Gallons per minute.	Diameter of Pipe in inches.
10	2	200	7
15	2½	220	7
20	3	240	8
30	3½	260	8
40	3½	280	8
50	4	300	8
60	4	350	9
70	5	400	9
80	5	450	9
90	5	500	10
100	5	600	12
120	6	700	12
140	6	800	12
160	6	900	12
180	7	1000	14

CHAPTER IX.

ROPES IN COLLIERY USE.

QUITE from the commencement of the writer's association with matters of colliery machinery—no date need be given at this point—he has always been warmly interested in the wear and tear of ropes used in colliery winding and in colliery haulage, and the interest has not diminished as time has gone on and experience has increased. During the second half of the nineteenth century great progress was made with regard to ropes manufactured for collieries. At the end of that century, and no doubt even yet, continental mining friends have never ceased their enamoured passion for ropes of some kind of fibre, and such material has not been confined to shallow mines. Our friends in Scotland, also, who can give the senior partner points in so many things, still remain more or less tainted with this absurd opinion. The writer has never been able to appreciate the slowness of a good many, even leading, Scottish mining engineers and colliery managers to adopt colliery mechanical equipment which has been proved up to the hilt in other parts of the United Kingdom to be the right thing. The writer did not come into existence south of the Tweed, and when asking relatives and other associates why they did not adopt such and such appliances in Scotland, has been startled by the cool reply, "Ah, weel, it would be mair expensive."

The continent of Europe may go on to decay with its fibrous material for colliery ropes, but such appliances are wrong, and will not be dealt with here. The writer has been able elsewhere to express how much the mining interest owes in the development of mining to the genius and pertinacity and success of iron and steel makers. There was a time, after the discarding of hemp, when the very best wire at disposal for rope production did not much exceed an ultimate breaking strength of twenty tons on the square inch, which would not give us more than a

safe working load of two tons in colliery winding, and the great bulk of the wire sent into the market and sold to rope makers was nothing like this strength; that limited either the depth or the load, or both. But iron wire, like iron plates, died a very slow death, and to a very large extent both have gone a good deal out of existence. The doctrine was preached, and had many fervent disciples, that steel could be used for a good many articles with which it was formerly associated, but for really reliable work, such as wire for colliery ropes, and plates for steam boilers, there was nothing that would do but iron. The doctrine was always fallacious, and its votaries were always mistaken. The fact was that when good iron wire or good iron plates were wanted, nothing of an inferior character was admissable, and the price a matter of indifference. In too many cases, in the early days of steel manufacture, the popular notion was that steel plates, etc., could be made of anything, and the disaster when the Tay bridge collapsed was an eye-opener; the structure might almost have been made of brown paper. When it was realised that steel productions, to be good, must be made from good materials, and that when such materials were used steel could be made of well-nigh any quality—that is to say, good—and that the price was a very serious reduction on that of iron, the production of steel appliances made rapid advance. It was not long before steel wire makers were able to place at the disposal of colliery rope makers a wire which reached an ultimate tensile strength of one hundred and twenty-five tons on the square inch, and furnishing a safe working load of twelve and a half tons per square inch. Such an advance meant a very great deal to the colliery owner and the colliery manager, because it enabled them to sink to a depth beyond which the deepest mines had not at the commencement of the twentieth century gone, and it enabled such a working load as would make possible an output to justify the depth. It will be well understood that the load upon a colliery winding rope includes the weight of the rope represented by the depth of the winding, and there is a limit not only beyond which a load of coals and cage and boxes cannot be attached with safety to the end of a winding rope, but there is a limit to the depth at which a winding rope can raise itself safely. We have mentioned that the exigencies of mining require a greater

area to be taken as the depth increases, and the appliances as well as the sinkings are a good deal more costly. It used to be suggested that feudal landlords and other ideally philanthropic persons established collieries simply to find the people employment. We do not hear so much of that now, and whenever the average citizen takes shares in a colliery concern his one aim is profit—it would be wrong to be otherwise. This means, of course, that as our expenses of getting to the coal, and our cost of appliances for raising that coal, increase, we have to recoup, or endeavour to recoup, by a larger output. Five hundred tons a day may be made a commercial success for a moderate depth of, say, 300 yards; but no one would think of putting down a colliery three times that depth and expect commercial success with such an output as has been named.

The question has forced itself upon the mind of the writer by the sittings of the Royal Commission on Coal Supplies, and to the consideration, amongst other points, as to the depth at which coal may be worked. There will be something to say about this matter, with regard to the cooling of the strata at great depths, in another section; but there is no doubt that this question of winding ropes enters in no mean fashion into the problem of deep mining. The writer does not know how a depth of four thousand feet was arrived at by a previous Royal Commission, and he has never accepted that as the limit of depth. The air of the mine will have to be cool enough to enable the men to work without excessive discomfort; on that head there need be no anxiety. The winding machinery will have to be sufficiently powerful and sufficiently economical for the greater depths. Power is what the engineer delights in providing, and economy in colliery winding will offer no difficulty when it has to be provided; but the remaining point is with regard to the winding ropes.

Assuming the ultimate tensile strengths already referred to—namely, one hundred and twenty-five tons on the square inch—it would appear that for a reasonable output, and allowing for the weight of the cage and the boxes and the rope itself, a limit is reached at three thousand feet. That depth is not satisfactory to the writer, and would necessitate a duplicate winding arrangement at the bottom of the first whenever we exceeded three thousand feet.

South Staffordshire is scarcely a leader in coal mining since the twentieth century commenced, but the district may still boast of coal-mining romancers. One gentleman, in a presidential address, said that we should have to get down to any depth that might be necessary by spiral inclines of fairly easy gradients, and on these inclines about thirty thousand tons a day would be brought to the surface by locomotives. Before that comes about there will be a statue erected to a departed genius by an admiring band of worshipers. The solution of dealing with coal from, say, depths of a mile will come about in one of two ways; either we must have a winding from the bottom, halfway, and a second winding for the second half of the depth. The writer's ambition is that colliery winding ropes shall be able to deal with loads from a depth of a mile. This would mean that a rope at the depth of a mile should not exceed the present weight for a depth of a thousand yards; and would thus leave the gross load of rope and cage and boxes the same at a mile in depth as at the present time for a thousand yards in depth. To accomplish this the material would have to be very substantially improved, and the ultimate tensile strength would have to exceed two hundred tons on the square inch. The writer had the honour and pleasure of the close acquaintance of excellent makers of steel, who, in their turn, are in close and constant touch with makers of steel wire. He has endeavoured to obtain some information on the subject, and has managed to this extent, that there is nothing fixed in the strength possible in steel wire, and that just as great advance was made in the last quarter of the nineteenth century because coal mining demanded the advance; there is no good reason why colliery necessity should not bring about a further substantial advance. What we have to say is, that taking as the present maximum with present strengths a thousand yards, each additional twelve and a half tons in the wire increases the depth at which ropes would be able to work one hundred yards. It will be noticed that no consideration is given to taper ropes to save weight, or ropes with taper cores to diminish weight; these things have been weighed in the balance and have been found wanting; to enable mathematicians to work out elaborate problems they were delightful, but for practical use were an abortion, and of course a failure. It has been considered better to treat the

question drastically. We want stronger wire for ropes; can we get it?

Of late years, not only has the material of colliery ropes been better maintained, but the ropes themselves have been better made and more intelligently used. Probably the ropemaker devotes a good deal more time in looking after the manufacture, and does not consider the selling of a rope the whole thing to be aimed at. So far as the maker of the wire is concerned, he ought to be compelled by law to keep records of the tensile strength and the ductility of every wire that he makes and sells for colliery use. The ropemaker should receive an official record of such particulars, and would thereby be in a position to make any one colliery rope of wire uniform in strength and ductility. No one would think of making a chain to raise and lower human beings with the links of different strength; then why should the wires of a colliery winding rope differ in strength and ductility? The ropemaker should furnish an official record of the ultimate strength and ductility of the rope itself. Then comes the rope user, who, having satisfied himself of a really good rope, should for winding purposes limit the load to come upon it, including itself, to one-tenth of the ultimate breaking strength. Such precautions will, perhaps, rather startle the average ropemaker and colliery manager, but every worker in the mine depends upon a winding rope for his life twice in each working day, and there should be no risks run. Any colliery manager running any such risks should be hanged; the other lives are valuable, his is not.

The precautions set out will not diminish the first cost, but that is not what colliery authorities should look at, and real economy does not rest there. Suppose a colliery winding rope costs one-half more, and during its lifetime raises three times the amount of material, the economy certainly does not attach to the rope which costs the least at first, and there is probably nothing in colliery machinery in which true economy is found more than in the highest quality of colliery ropes.

One is almost ashamed to have to introduce in this work in this age any reference to other than round ropes for colliery use, but such are not universal, and flat wire ropes have not by any means passed away. Some urge that they give the

advantage of providing a certain amount of what we call compensation by coiling one coil upon another; others say that such a rope has so massive an appearance that the collier actually revels in its apparent safety. We are also told that a flat winding rope never has the slightest tendency to twist; as a matter of fact flat ropes will twist, and round ropes need not twist. Then it is said that a flat rope cannot slip; this is only partially true, and whilst the drums on which flat ropes work ought to prevent slipping, and can prevent slipping when properly constructed, this latter condition rarely applies; flat ropes can slip and have slipped.

An endeavour has been made in what might be called fairly good arrangements to strengthen the arms of drums of flat winding ropes, by making the arms strong in themselves and very much stiffened by channel iron placed at the back of each arm. A better way is to build the drum up as a metal structure, and to have on each side a ring faced on the inside and firmly fitted so that springing out is impossible. But the proper remedy is to consign these barbarous relics of a heathen age to oblivion. There is still another danger to which flat ropes are liable. It is all very well to say that they give us a perfect and unvarying line of communication between the drum and the headgear. They ought to do so, and with proper care in erecting the plant would do so; but there are cases in which that absolutely-perfect line is not provided, and the kink at the drum and the kink at the headgear pulley will inevitably do serious injury to the rope. To show how much can be done with care, the writer had charge of the erection of the plant to work from a depth of over six hundred yards. The headgear pulleys were not a great deal wider than the rope, and the same remark applies to the width between the arms of the drum—probably half an inch was the amount of play in each case. He must ask his readers to believe that having flat ropes at all was against his wish; but colliery engineers, even when they are authors, are like other mortals, and do not get all their own way. The proper amount of care was exercised in the erection of the plant; and although a good many years have elapsed since then, it is very questionable if the edges of the ropes have ever touched the flanges of the pulleys or the arms of the drum.

Figs. 290, 291, and 292 (*see sheet* 11, *between pages* 486 *and*

487) give representations of winding drums for round ropes. Fig. 292 represents the cylindrical drum, and as it has no compensation in itself, such provision has sometimes been made by means of a tail rope, the two ends attached to the bottoms of the two cages, and the lower end of this tail rope passing round guiding timbers in the sump. This, of course, would give perfect compensation, because there would always be the same weight of rope attached to each side, provided the tail rope was uniform in size and weight with the tail rope. This principle was afterwards extended in what came to be known as the Koepe system of winding, in which the winding drum was replaced by a winding pulley, and one winding rope was applied instead of two. Theoretically, this system was an ideal one; it enabled the rope to travel always in the same straight line, and to work on the same size of circle. The massive winding drums were made unnecessary, and, of course, the working of the winding appliances was more easy. It seemed as if in one respect, at any rate, something like perfection had been reached, and, no doubt, very considerable success attended the application in several cases. But for very deep winding, where heavy loads are inevitable, it would be found impracticable to ensure the requisite grip by a rope passing simply half way round a drum pulley; the size of such a pulley would be too great. Then, as depth of pit shafts increased, the length and weight of ropes had to increase, and the speed of winding also advanced. It does not seem likely now that we shall have any general adoption of the Koepe system of winding, notwithstanding the fact that some improvements have been effected as regards the grip. Our readers will note that the winding rope is always kept comparatively taut by the load at one end and the pull at the other end; but this is not the case with the tail rope, and a weight of perhaps ten tons free to bang about in a pit shaft half a mile deep, and the cages running at a speed equal to the fastest express train, can hardly come within the range of what we call safety in colliery operations. Fig. 290 represents what we call a conical drum, which years ago was fairly popular, and, affording as it did a substantial amount of correction for the inequality of the load in winding, was a simple and popular appliance. In several cases the rope slipped from the higher coils to the lower, and this conical drum got into disrepute; but wherever accident

occurred it was easily proved that the winding drum and the headgear pulley had been wrongly arranged; if the headgear pulley is placed in line with the highest coil of the drum the rope will not slip; on the other hand, if appliances are wrongly placed accidents are inevitable.

Although first applied in the Wigan coalfield in the early part of the second half of last century, there is, perhaps, no better winding drum now than the spiral drum, and the probability is that the deep mining which has to be faced will give an impetus to the application of this drum in the present century. As now made of strong steel plates it is much lighter than formerly; there is a space for a few parallel coils at the bottom of each side, and for a few parallel coils at the top of each side; the inclination of the sides is practically as great as enabling the coils to miss each other will allow; and the minimum and maximum diameters are simply a matter of calculation based upon the particular data—that is to say, the weight of ropes, cages, tubs, and coals. The depth comes into the calculation as regulating the space to be allowed for the ropes coiling. Specially grooved iron or steel forms the spiral, and the rope, with great advantage and absolute security, coils in this special spiral.

The writer, referring back to his remarks on very deep mining, is unable to see how any other arrangement can be applied with such effectiveness as this spiral winding drum. Ropes have quite remarkable lives working on these drums, and have, even when discarded by age, been found equal to very severe tests. A colliery winding rope, properly made of proper material and properly used, might well enough give full work for half a score of years.

In the old days all our colliery wire ropes were built up of strands twisting round a central core, and each strand having its number of wires. The gospel of ropemaking then was that the wires of each strand should twist in one direction, and the strands themselves should twist in the opposite direction. The defect of this arrangement was twofold. First, the bearing surface of each rope was simply a collection of projections, inviting excessive wear at these points; secondly, there was nothing to prevent the entry of moisture into the rope, which played havoc with it in a very short time. Two very striking

improvements have been made. First, that identified with the name of Lang, and first introduced by the inventor at the works of Cradock, of Wakefield. In this rope the wires of each strand and the strands themselves twist in the same direction; the bearing surface is materially increased, and the life of the rope is proportionately increased. The other improvement, known as the locked-coil rope, has been identified with the firm of George Elliott & Company, and is really a very marvellous structure. Looked at in cross section there are

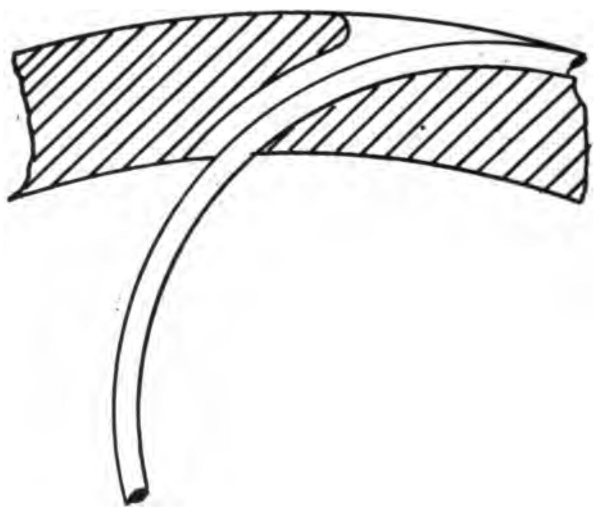


FIG. 296.
ROPE PASSING THROUGH DRUM CORRECTLY.

several concentric rings, each ring simply lying upon the ring beneath it, and each ring composed of wires which lock into each other and which coil from end to end of the rope. There are no strands, and the rope, looked at from the outside, presents a complete and continuous surface without the slightest projection at any point. Nothing can get into the rope, and that abomination, internal corrosion, is claimed to be impossible. The locked-coil rope is free from any propensity to twist, and possesses that virtue to an extent unknown in any other type. It is also more flexible than any other make of rope, and a locked-coil rope similar in size and of similar material is stronger than any other make of rope. There is, no doubt, a higher cost, but enough

has been said to show that the first cost of colliery winding ropes may furnish most misleading comparisons.

A common defect in drum arrangements is that the rope, in passing through the rim into the interior to be secured, makes a very sharp curve. Figs. 293 and 294 represent what the writer considers a right and a wrong way of passing the rope into the drum. So serious is the defect of fig. 294 that ropes on examination have actually been found broken at this point, and safety has depended on the grip of the coils which never leave the drum. This grip, by means of what we call coil friction, is very great, and even a single coil will enable a force of one pound to withstand a load of nine pounds; and as the effect increases almost geometrically, we can understand that the

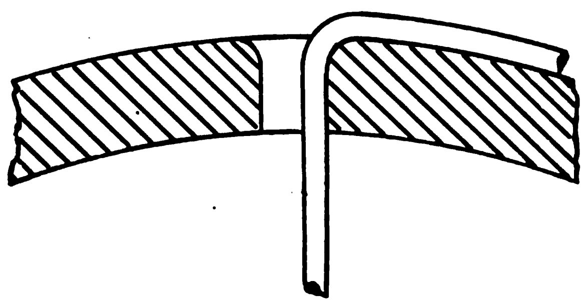


FIG. 294.
ROPE PASSING THROUGH DRUM INCORRECTLY.

"clams," which secure the rope within the drum, have very little to do. The securing of the winding rope to the cage attachments is very important, and may be performed in a way certain to be injurious to the rope. The proper method of what we call capping should fulfil the following conditions:—The increased pull should tend to the security of the capping; that evidently means that the capping must fit a taper end of the rope, increasing in size to the end. Nothing should pass through the rope, because doing so must either break some of the wires or open the rope itself. The proper arrangement is to have a split capping admirably fitting the taper end of the rope; the exterior of this split capping, when in position, should have a slight taper, and on this exterior strong and well-fitting hoops of steel should be driven. (*See page* 497 *et seq.*)

A good deal used to be heard as to the necessity of frequent recapping of winding ropes, a period of three months being often taken as a maximum. It was said that the capping was weaker than the rope, and that there was a liability to buckling at the top of the capping, where the rigidity of the capping ended and the elasticity of the rope commenced. It was also said that a rope resting on the headgear pulley, exposed to the weather at one place for hours together, was liable to suffer, and each recapping removed this point of location. At the present day a capping can be as strong as the rope, and careful engineers and careful banksmen, by avoiding so much slack rope, can prevent buckling. As to the resting of the rope at one point for a lengthened period, the harm with good ropes and good pulleys will be infinitesimal; but if there is any injury the remedy would be to cut off the rope as far as would remove the part supposed to be injured. No hard and fast line can be laid down, and the writer is quite content to state his opinion that *excessive* recapping is undesirable; generally, twice or three times a year should suffice.

A good deal of injury can be done to a winding rope by making the horizontal angular travel of the rope too great, the injury being by reason of the grinding of one coil upon the side of another, which, it must be remembered, is provided against in the spiral drum. All collieries do not use spiral drums, and we have to recognise this in these pages. The representatives of ropemakers have a great fad about what they call the lead of a winding rope, and put on the look of greater cleverness than any man can possess when they speak of it. By this term "lead" they mean the angle in the vertical plane at which the rope leaves the drum and enters the headgear pulley, and if some of them could have their way they would make this angle 90 degrees; that is to say, the rope would be horizontal, and the drum and headgear pulley on a level. Now, what can it matter what this lead is? A rope receives no more injury passing round half the circumference of a good headgear pulley than it receives in passing only a quarter round; and as regards the drum, the rope in any case has to pass round and round it over and over again. Ropemakers' lead is a figment of the imagination. What does matter is the horizontal travel, which diminishes

with the increased size of the drum and increases with depth of winding.

The writer obtained some very excellent results at a pit shaft 400 yards deep, when the side travel at the drum did not exceed 30 inches—say 3 feet—when the horizontal distance from the centre of the winding drum to the centre of the headgear pulley was not less than 30 yards. The drum was about 15 feet diameter, and upon this basis, knowing the depth of shaft and size of drum, and keeping to the same horizontal angle, we could determine a satisfactory distance from the drum to the headgear pulley.

Something might be said as to the great danger to ropes arising from drums being too large, or the engines connected with them having insufficient power, necessitating a jerk commencing a journey. The influence of a steady load, when within the capabilities of the rope, is not harmful, and we know what it is; but the effect of a jerk is not easily measurable, and may multiply, at the moment, the load several times. Suppose we separate each winding into three parts: first, getting up speed; second, running at full speed; third, retarding speed: then, even with good arrangements, during division one the pull on the rope is substantially in excess of the load; in division two the pull on the rope is equal to the load; in division three the pull on the rope is less than the load. This we can provide for, but a jerk at the commencement of a winding is an exaggeration which is absolutely unsafe.

The size of drums and pulleys upon which ropes should have to work is worth attention, and, of course, must be regulated to some extent by the engine arrangements and the determined minimum size of the winding drum. Ropes are better made now, and do not absolutely require such large circles to coil on effectively as formerly; but even now it is not desirable to have these circles less than a hundred times the diameter of the rope, and the headgear pulley, whilst it may well be larger, should not be less than the minimum size of the drum. As to the rims of headgear pulleys much care is necessary now, because, whilst formerly the pulley was harder than the rope, and the latter had to suffer, now the rope is harder than the pulley, and the pulley wears away. Steel has not yet established itself to any great extent for this pur-

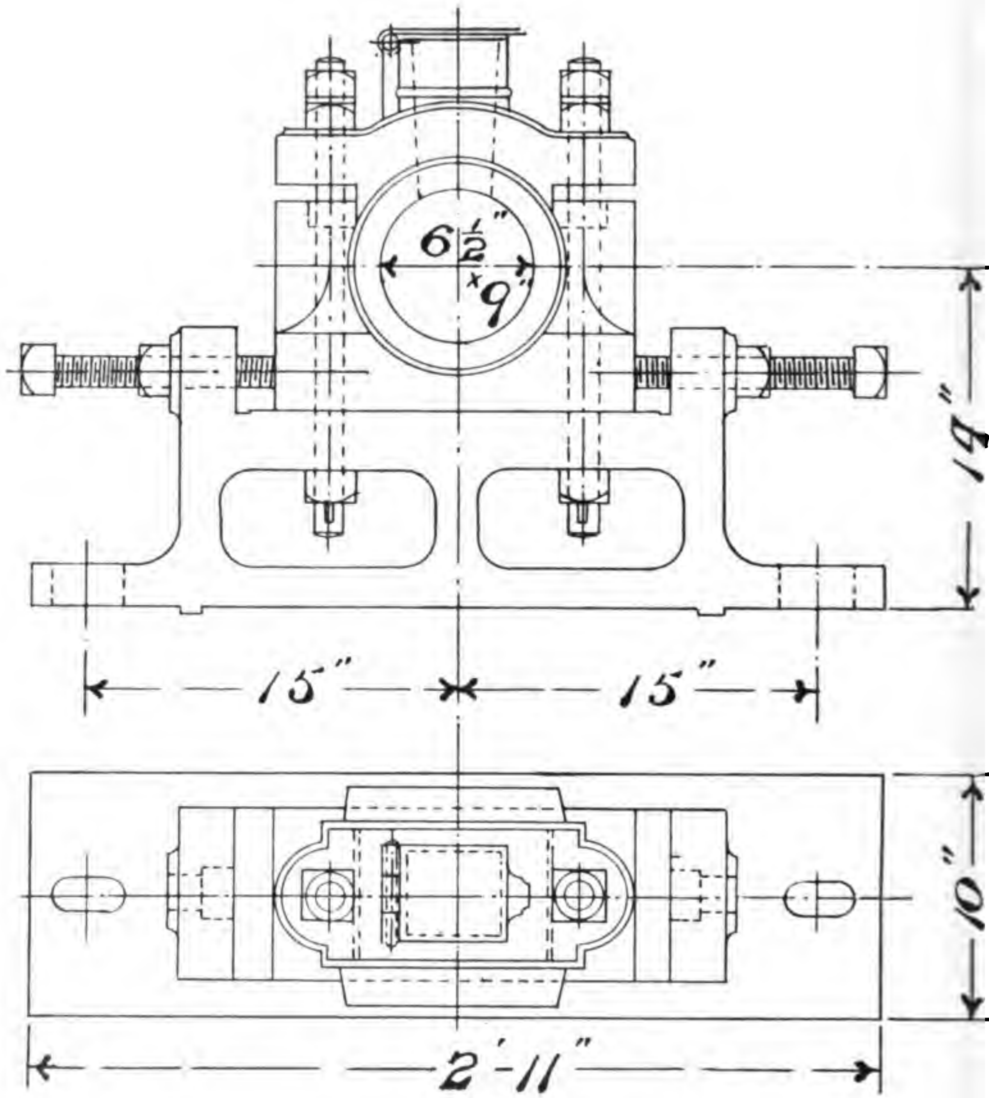


Fig. 295.

Adjustable Pedestal for Headgear Pulley. Messrs. J. Wood & Sons Limited, Wigan.

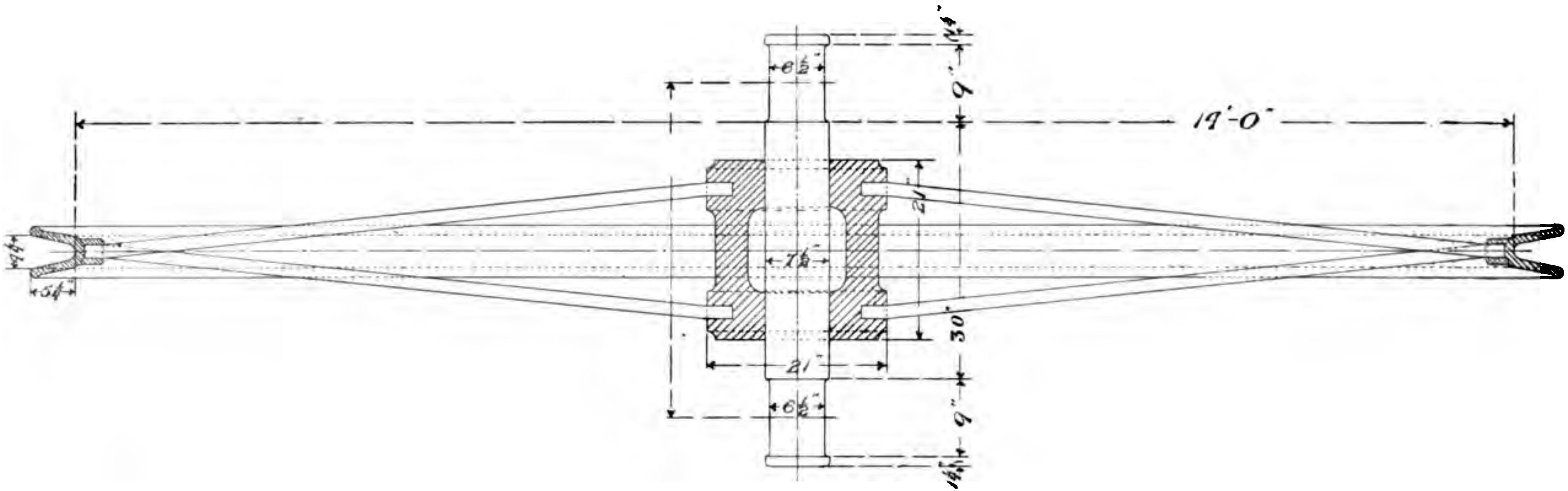


Fig. 296.

Section of Round-Rope Headgear Pulley. Messrs. J. Wood & Sons Limited, Wigan.

pose, and cast iron answers very well for the rim as well as the boss.

Not long ago a perfect headgear pulley was considered to be one turned by machinery in the working groove of the rim. That is hardly the case now. Such pulleys, of any size up to, say, twenty feet diameter, can be cast with a sufficient approximation to roundness in the groove, and some users prefer to leave them unturned, so as to get the benefit of the hardness of the natural skin. Figs. 295 and 296 (*see pages* 492 *and* 493) represent a headgear pulley and pedestal. Whilst on this point of headgear pulleys—although not quite, perhaps, within its own section—we may without disadvantage revive the old question, What is the proper form of groove of the headgear pulley? For a round rope the sweep of the groove should be slightly larger than the circle of the rope, and the sides taper away slightly. It used to be said with regard to flat ropes that the rim, after the fashion of pulleys for leather straps, should be slightly convex to ensure the rope running in the centre of the groove. The circumstances are not the same, and a flat winding rope is not a solid structure, like a flat leather strap, but is a built-up structure of four or six or eight round ropes stitched together. If all these round sections of the flat rope are kept under equal tension the rope works well, provided the rope itself is a good one; if the equal tension does not prevail, the rope becomes a loose combination of wires.

The headgear pulley which answers best for avoiding this is one with a flat and horizontal working surface from side to side of the rim.

It may be taken for granted that all well-managed collieries keep records of the work which winding ropes have done. In addition to the particulars in the office as to the maker and the quality and the size and the price, it is the fashion to have in the winding-engine house a rope board; it affords useful information which need not be kept from anyone, and as the winding engineman has considerable influence upon all his machinery, including the rope, the information is such as he should have constantly before him. The writer submits a simple outline of a rope record to be placed in winding-engine houses. There is no genius in it, and there will be no trouble about patent rights.

THE EMPIRE COAL COMPANY.

KING EDWARD VII. PIT.

Depth 820 yards.

Right-hand Rope :—

Put on new..

Capped..

Last rope worked....................................

And made...................................*Windings*

And raised.............................*Tons of coal*

Left-hand Rope :—

Put on new..

Capped..

Last rope worked....................................

And made...................................*Windings*

And raised.............................*Tons of coal*

....

Manager.

It will be observed that the number of windings is set out as well as the weight of coal raised. The fact is that the real test is the number of windings, because, always provided that the maximum load is never in excess of the safe working load, the wear upon the rope for each winding is much the same whatever the load.

In this work no attempt is made to set out detailed particulars of capabilities of ropes of different qualities, because, after all, they are only what the cards of the ropemakers tell us that the capabilities should be, and if we relied upon them, the less scrupulous ropemaker, by giving higher figures, would simply reign supreme. We have taken, as will have been noticed, quite a different line, and if our conditions were fulfilled of furnishing an official test of every rope, we should know exactly what we were buying, and there ought to be no difficulty at all in having an official test of every rope. If these official tests were made and placed upon the makers' cards, then such cards would be of service. Adhering pertinaciously to our regulation that none but the highest quality of steel wire should be used for colliery ropes, and assuming the ultimate

tensile strength of such to be 125 tons to the square inch, the following figures are given for what they are worth; we are dealing only, of course, with round ropes:—

Circumference, in inches.	Diameter, in inches.	Approximate weight, in pounds per fathom.	Breaking Strength, in tons.	Safe Working Load. Tons.	cwts.
1	·318	1·0	4·75	..	9½
1⅛	·358	1·26	6·25	..	12½
1¼	·397	1·56	7·75	..	15½
1⅜	·437	1·90	9·00	..	18
1½	·477	2·25	10·25	1	0½
1⅝	·517	2·63	12·75	1	5½
1¾	·557	3·00	14·75	1	9½
1⅞	·596	3·50	17·25	1	14½
2	·636	4·00	20·50	2	1
2⅛	·676	4·50	23·50	2	7
2¼	·716	5·00	26·00	2	12
2⅜	·756	5·60	28·50	2	17
2½	·795	6·25	32·00	3	4
2⅝	·835	6·80	35·00	3	10
2¾	·875	7·50	38·00	3	16
2⅞	·915	8·20	40·50	4	1
3	·955	9·00	43·50	4	7
3⅛	·994	9·70	47·00	4	14
3¼	1·034	10·50	50·00	5	0
3⅜	1·074	11·30	53·00	5	6
3½	1·114	12·25	61·00	6	2
3⅝	1·174	13·00	63·00	6	6
3¾	1·193	14·00	68·00	6	16
3⅞	1·233	15·00	72·00	7	4
4	1·278	16·00	78·00	7	16
4⅛	1·313	17·00	80·00	8	0
4¼	1·352	18·00	88·00	8	16
4⅜	1·392	19·00	92·00	9	4
4½	1·432	20·25	101·00	10	2
4⅝	1·472	21·60	104·00	10	8
4¾	1·532	22·50	106·00	10	12
4⅞	1·551	23·70	112·00	11	4
5	1·591	25·00	119·00	11	18
5¼	1·671	27·50	134·00	13	8
5½	1·750	30·25	147·00	14	14
5¾	1·830	33·00	160·00	16	0
6	1·909	36·00	173·00	17	6
6¼	1·989	39·00	187·00	18	14
6½	2·070	42·25	204·00	20	8

ADDITIONAL USEFUL NOTES ON COLLIERY ROPES.

The following notes and the table of weights and strengths refer to the ordinary round wire rope (Lang's lay), consisting of six strands of seven wires each, with hemp core.

To find the weight of a wire rope: The circumference of the rope in inches squared is a sufficiently close approximation to the weight in pounds per fathom for all practical purposes.

The weight in pounds per fathom multiplied by 4½ will give approximately the breaking strength of a first-class quality rope in tons.

The breaking strength in tons multiplied by 2 gives the safe working load for winding in hundredweights—that is, one-tenth of the breaking strength.

For haulage ropes allow a factor of safety of from 6 to 7.

Nearly all ropemakers of repute manufacture several qualities of rope of wire having a tensile strength of from 100 to 125 tons per square inch of sectional area. The wires having the higher strengths are known in the rope trade as "plough" steel wire. This is purely a trade description; strictly speaking, these high-grade wires are high-quality crucible steel.

To ascertain approximately the size and weight of a high-quality round steel winding rope for a given load and given depth of shaft: Take the total weight of the maximum load to be attached to the end of the rope in pounds—that is, the weight of the cage, tubs, coal, chains, etc.—and divide by the difference between 2000 and the depth of the shaft in yards. The result gives the weight of a suitable rope in pounds per yard, giving a factor of safety of 10, and including the weight of the rope itself. Example: A load of 10 tons at the end of the rope in a shaft 700 yards deep:—

$$\frac{2240 \times 10}{2000 - 700} = \frac{22{,}400}{1300} = 17{\cdot}23 \text{ pounds per yard,}$$

or $34\frac{1}{2}$ pounds per fathom. The square root of this figure will give, approximately, the circumference of the rope in inches—namely, $5\frac{7}{8}$ inches.

The above rule has been arrived at in the following way:—The weight of 20,000 yards' length of any size of round rope of best quality is practically equal to its own breaking strength; thus, a rope weighing 9 pounds per fathom would give a strength of about 40 to 42 tons, or rather over 90,000 pounds, and 90,000 divided by 9 gives 10,000 fathoms, or 20,000 yards.

Following the line of argument further, it will be seen that the weight of 2000 yards' length of rope will equal its own safe working load; if, therefore, we deduct from the 2000 the depth of the shaft in yards, to allow for the weight of the rope itself, and divide the difference into the load suspended from the end of the rope, we get the result as stated.

CAPPINGS FOR COLLIERY WINDING ROPES.

The Increase of Strain due to Acceleration of Speed.

The present writer has often been struck with the fact that, in colliery practice, the question of load on winding ropes, due to acceleration of speed, is rarely, if ever, taken into account.

It is quite certain that there are not a few colliery engineers and managers who are entirely unconscious of its existence, much less its effect.

That a greater force is necessary to set a weight in motion than will suffice to keep it in motion at a constant speed when once set moving, is a fact with which most of our readers are doubtless familiar. The extra force is necessary in order to overcome the inertia of the body—the tendency to continue in a state of rest when motionless, or the tendency to continue in motion when moving. Suppose we have a weight of a ton suspended by a rope, and this weight we commence to raise very slowly, the strain upon the rope will practically amount to one ton; but if, on the other hand, the weight be raised with a quickly-increasing velocity, amounting to an acceleration of 32 feet per second, the strain on the rope will no longer be one ton, but exactly twice as much—two tons.

As a matter of fact, the extra strain due to acceleration amounts to 70 pounds per ton for each foot per second in the rate of acceleration. In the case of colliery winding engines there can be little doubt that, in innumerable instances, the rate of acceleration at the commencement of winding, for a second or so, approaches 32 feet per second, and this means that for the moment the strain upon the winding rope and capping is equal almost to twice the weight of the loaded cage.

A similar increase of strain is produced, too, at the end of the wind, especially if the brake is too powerful, or is applied in such a manner as to check the engines suddenly.

It will be accepted as a fairly general rule that the factor of safety in a colliery winding rope should be 10; that is to say, the breaking strength of the rope should be ten times as great as the maximum load, which should include the weight of the loaded cage plus the weight of the rope itself. Bearing in mind, however, that the strength of a chain is the strength of its weakest link, and, similarly, that the strength of a winding rope, between the drum and the cage, is the strength of the weakest point, it is to be feared that we do not always realise how very frequently the factor of safety, in actual and ordinary winding, is nearly all absorbed.

Assume, as an example, a total load, cage plus rope, of 10 tons, the rope should have a breaking strength of 100 tons. At the

moment of starting the actual strain may, for a second or so, approach 20 tons, thus reducing the factor of safety to 5. There is, however, an additional element of weakness, tending to still further reduce the margin of safety—namely, the capping, which it has been proved rarely has a strength amounting to much more than 50 per cent of the rope.

We are indebted to Mr. F. L. Ward, the general manager of the Bradford Colliery, Manchester, for a considerable amount of useful information of one kind and another, not the least important being that relating to rope cappings.

The Bradford Colliery, occupying, as it does, a position almost in the very heart of a great city, the city of Manchester, is unique amongst collieries. Unlike most other collieries, space on the surface is not only exceedingly limited, but also very valuable, and the equipment of a colliery so situated is calculated to tax the ingenuity of the most resourceful engineer. The present condition of the Bradford Colliery, and the nature of the further developments now progressing, amply bear testimony to the fact that in the person of Mr. Ward it possesses an engineer and manager with the full complement of ingenuity and resourcefulness.

At the moment of writing a shaft is in course of sinking at the Bradford Colliery, now over 600 yards deep, which, when completed, will rank amongst the deepest in Great Britain. The new vertical winding engine—vertical because there is not room for a horizontal engine—with its 25-foot diameter built-up steel drum, and its 42-inch by 6-foot cylinders, is one of the best examples of a modern colliery winding engine which has come under our observation.

At a colliery where space on the surface is so limited, one is not surprised to find that full advantage has been taken of the compactness of electrical power plant, and, with the exception of the winding engines, practically all the power used above and below ground is electrical. The power house contains two 150-kilowatt sets, Johnson-Lundell continuous-current dynamos, made by J. H. Holmes & Company, of Newcastle-on-Tyne, direct coupled to Browett & Lindley vertical high-speed compound engines; a 350-kilowatt dynamo by the same makers, coupled to a three-cylinder compound Browett & Lindley engine; a 15-kilowatt lighting set, and a

motor generator. The current for power purposes is generated at 525 volts, the lighting dynamo works at 230 volts, and the motor generator is intended to serve as a stand-bye lighting set, the motor side working at 525 volts and the generator side at 230.

To return, however, to the subject in hand—the design and strength of rope cappings. As the result of an accident, fortunately not attended with personal injury or loss of life, Mr. Ward was led to make a number of tests—or rather to have a number of tests made by responsible experts at the Sheffield testing works—with the object of ascertaining the relative strength of different types of cappings, and, if possible, effecting improvements.

We would like to remark here that Mr. Ward has formed a habit which might well be copied by all colliery managers. Whenever an accident happens, due to the breakage or failure of some appliance, or part of an appliance, if his investigations lead him to suspect that the design of the appliance is at fault, and capable of improvement, he immediately discards not only the individual defective appliance but all others of the same kind which may be in use, substituting an improvement. The ingenious tub-coupling link, the best appliance for the purpose we have seen (described in the section on "Haulage"), is a case in point. This link was the outcome of an accident, caused by the breaking of the ordinary type of coupler, the type used at most other collieries.

In the present instance Mr. Ward satisfied himself that the usual rope cappings, even the best of them, are not what they should be. Cappings most carefully made, on the lines advocated by several of the leading firms of ropemakers, when submitted to the testing machine either drew or broke inside the capping, with a strain very little more than half the strength of the rope. The usual type of split conical-shaped socket, in which the rope end is prepared by turning back the wires and threading into the rope so as to make a conical end to fit the socket, was the type formerly used at Bradford Colliery. One of these cappings—most carefully made, and fitted with no less than five rings, the capel itself being 3 feet long—began to draw at 12 tons, and continued to move until the strain amounted to 28·35 tons, when the rope broke inside the capping and came out. The breaking

strength of the rope was between 42 and 43 tons. This was repeated several times with similar results.

Very naturally these tests put an end to all confidence, in Mr. Ward's mind, in what is generally regarded to be the best type of rope capping. He determined to supplant it with a more reliable form of attachment, and there can be little doubt that the type of capping illustrated and described in this and the following pages is quite one of the most perfect and strongest methods of capping a winding rope. The most pleasing feature is the fact that, whilst being, perhaps, the strongest and safest capping in existence, it is also the simplest and the easiest to make; a rope can be recapped with this form of capping in less than one-quarter of the time required for other types.

The source of weakness in other cappings would appear to be in the fact that it is not possible to grip each separate wire in the rope equally. In Mr. Ward's capping each individual wire is securely held, and thus performs its proper share of the work. The capping is shown in fig. 297. (*See page* 502.) The cone-shaped socket is forged from a solid piece of steel, with the lugs formed at the lower end through which the bolt is passed. The internal length of the cone is 8 inches, with 1 inch of taper; that is to say, the diameter of the hole at the widest part is 1 inch larger than at the narrowest end. The rope is prepared by binding a few turns of soft wire round it 8 or 9 inches from the end; this short length is now untwisted, and each wire separated from its companions and straightened out to some extent. To remove the grease from the wires the rope end is washed in petroleum and dried carefully over a coke fire. Powdered resin is now dusted on to the wires and blown in between them with a tube, after which the prepared end is drawn into the socket, which, warmed just too hot to bear the hand upon, has been previously threaded on to the rope. The socket is inverted, and, as quickly and as carefully as possible—two persons at opposite sides pouring simultaneously—a melted white metal is poured into the socket, flowing round the wires and adhering to them. The wires are, in point of fact, soldered together into one solid cone-shaped mass of metal, each wire being securely and separately held.

The white metal is composed of 70 per cent magnolia metal and 30 per cent pure tin. Mr. Ward has been careful to

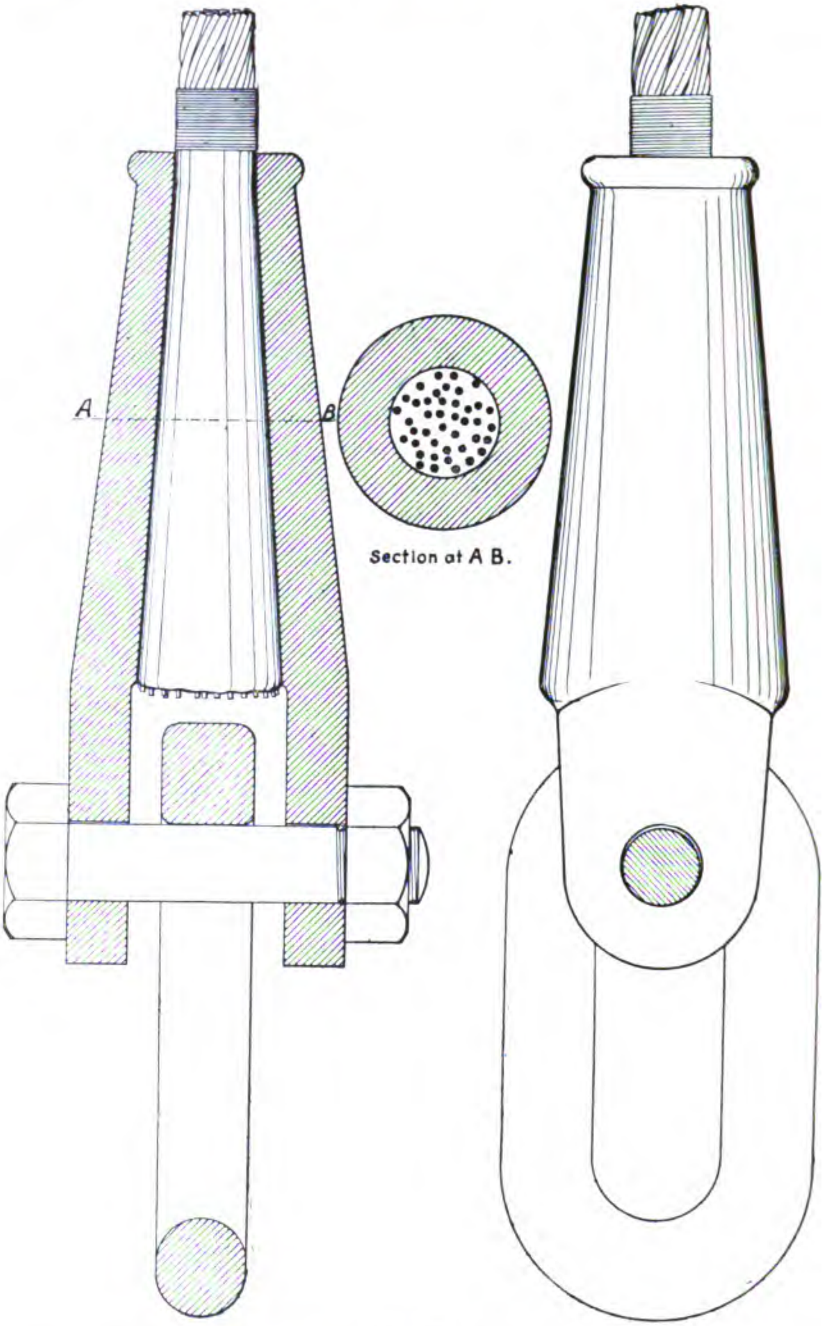


FIG. 297.

WINDING ROPE CAPPING. APPLIED BY MR. F. L. WARD, AT THE BRADFORD COLLIERY, MANCHESTER.

ascertain from steel experts and wiremakers, as well as the experts at the testing works, that the temperature of the melted metal cannot injuriously affect the temper or the strength of the wires.

In the testing machine this capping has given astonishing and highly-satisfactory results; not in a single instance did the rope break inside the capping—always clear away, and without any appreciable movement of the rope in the capping as the strain was increased.

The strength of the rope used was, as already stated, between 42 and 43 tons, and whilst the other cappings allowed a considerable movement of the rope, with final breaking *inside* the capel at very little more than half the strength of the rope, the improved capping *only drew to the extent of ·02 to ·11 of an inch with a strain of 35 tons*, the rope finally breaking clear away from the capping at 42½ and 43 tons.

The capping is now in regular use at the Bradford Colliery; its simplicity should recommend it to every colliery engineer, and we understand that Mr. Ward does not intend to impose any restriction to its adoption by others. It would appear to be equally applicable for hauling ropes as for winding ropes.

The points requiring special care in its construction are the careful cleaning and separating of the wires, which must be spread out into a cone shape and properly resined, and the quick and even pouring of the melted metal, which must not be overheated and which must be of the right composition.

An important feature is that the actual end of the rope, or, rather, the ends of the wires, protruding below the cone of white metal, can be seen at any time when inspecting the rope and capping, thus enabling the rope inspector to make positively certain that no movement has taken place.

CHAPTER X.

PIT-SHAFT GUIDES.

THERE was little necessity in the early days of mining to pay much regard to the guiding arrangements in the pit shaft. The depth at which coal was worked was not considerable, and the speed of winding was very inconsiderable. As a proof of this latter condition of things it has been told by the ancient miner—who, like the Ancient Mariner, never diverged from the truth—that the common practice was for the winding engineman to commence a winding and to fire up at his boiler during the winding, returning in due course to stop his engine. In the writer's early days in the Black Country there were many pit shafts which had no guides at all, and the occupants of the skip kept themselves from rude contact with the rugged sides of the pit shaft as best they could. Of course, in those days only one rope worked in one pit shaft, and this made the primitive methods of our forefathers possible. But depths increased, and loads increased, and it became not unusual to have two winding ropes working in one pit shaft. It may be well to state what generally constitute the necessities of guides in pit shafts. We want to compel a vertical movement of the cage, and that would be impossible without guides, because a cage suspended at the end of its rope will move about horizontally over the shaft by the influence of a puff of wind. This vertical movement is essential to keep the cage from coming in contact with the sides of the pit shaft, and also, with two ropes in one shaft, to prevent collision of the cages, which in any case would be disastrous, and with men in either cage would probably be fatal. Pit shaft guides were first of all made of wood, measuring from four inches square in cross section to something more, running from top to bottom of the pit shaft, attached at distances of about ten yards to horse-trees, and having upon each side of each cage shoes working up

and down the wood guides. A defect of these was that they were liable to break, and, of course, such an incident was likely enough to have serious consequences. To avoid this tendency to break guides which were practically railway metals were introduced, and they did not break. (*See figs.* 298 *and* 299.) There are in use at the present time guides of wood and guides of metal; the writer is not in favour of rigid guides of either material. The placing of such guides in a pit shaft, especially when deep, is a costly matter; and it does not appear that any rigid system of guides in pit shafts will allow what is so necessary in winding—namely, absolute freedom by giving a true vertical line. An ordinary building always shows settlement, and it will be accepted without question that there

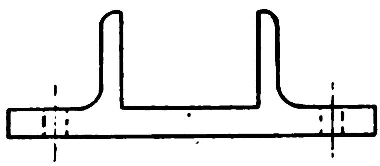


FIG. 298.
CAGE SHOE FOR WOODEN GUIDES.

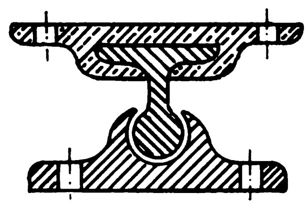
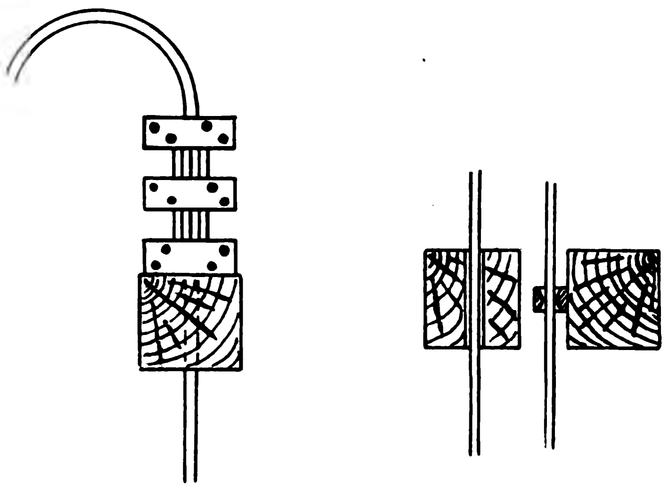


FIG. 299.
STEEL RAIL GUIDE.

will be settlement in a pit shaft hundreds of yards in depth. All such settlement is a disturbance, and dislocates the vertical line of the guides.

The ideal pit-shaft guide is what is known as the wire conductor, which is practically a wire rope of thicker wire. These wire conductors pass from the top of the pit shaft to the bottom, and have no connection except at the two extremes; there are no horse trees in the shaft, and this avoids not only great expense, but an awkward obstruction. Settlement of the pit shaft has no influence, and variations of length by variations of temperature are provided for automatically. The cage slides upon the wire conductors, and as they give and take for every breath that blows, the freedom of winding is not interfered with at all. The methods of securing wire conductors has been one of growth and development, and the writer has somewhat modified views formerly held upon this subject. A favourite method was to attach the upper end in the headgear and tighten the conductor up by means of a screw under a sill

at the bottom of the pit shaft. Theoretically this might do, but practically it is a most dangerous arrangement. If the shaft temperature decreases, the length of the conductor will diminish, and probably the strain will become so great that it will break; if the temperature of the pit shaft increases, the wire conductor will lengthen, and becoming slack will be useless. Suppose the temperature does not vary, the conductor itself will tend to stretch, and in being tightened up an infinite pull may be put upon the conductor, and ultimately it will break. Lives have been lost by the breakage of wire conductors under such conditions, and they must be pronounced as absolutely unsafe.



A Attachment in the Headgear. B Steadying Arrangement at Pit Bottom, above the Weights.

FIG. 300.

DETAILS OF CONDUCTORS.

Figs. 300 and 301 illustrate the attachments of wire conductors in the headgear and at the bottom of the shaft, and also the weighting of the conductors at the bottom of the shaft. A few years ago a good practice was to have the weights upon the wire conductor placed at the bottom of the pit shaft, and, without attempting any mathematical accuracy, there is no good reason why it should not be accepted that the needful rigidity of each wire conductor was obtainable by a weight amounting to one ton for each 200 yards of depth. This rapidity is only comparative, because in a pit shaft half a mile in depth there might be as much weight on the end of a wire conductor

as it could safely support, and yet half way in the pit shaft a gentle pressure of a finger would move the conductor across the shaft. In most cases, even now, this method of weighting wire conductors is in vogue, and certain simple requirements should receive attention. The weights at the bottom of the wire conductors should have no solid debris accumulating underneath so as to become dangerous. The receptacle at the bottom of the pit shaft often contains a good deal of water, and the only effect that has is to diminish the effective weight on the conductors by two-fifteenths. Of late years a system has grown up of applying the weights on wire conductors at the top of the pit shaft, and

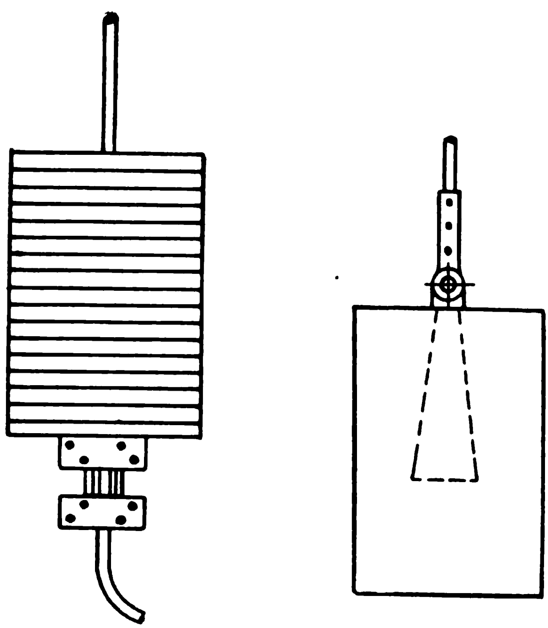


FIG. 901.
WEIGHTS FOR CONDUCTORS.

although the writer was anything but enamoured of this arrangement at first, he does not rank himself with the opponents at present. Of course, with the system of weighting the conductors at the bottom, we get the benefit of the weight of the conductors themselves, whereas in weighting at the top we have to apply not only the weight which would be applied at the bottom, but we have also to apply a sufficient weight to make up for the loss of

the influence of the conductors themselves. But suppose we have a fairly deep pit shaft, say half a mile in depth, each conductor will be weighted with four tons, and the whole arrangement for two cages, reckoning the weight of the conductors themselves, would be very great indeed upon the headgear.

The modern method at some really good collieries is to simply secure each conductor at the bottom of the pit shaft, and allowing the upper extremity to pass over a pulley in connection with the headgear, and place the needful weight at the end. There is this unquestionable advantage, that instead of the weighting influence being in the hidden regions of the bottom of the pit shaft, where practically nobody ever sees it, the whole system is well within the light of day and under easy supervision.

We might have mentioned in dealing with ropes the matter of inspection, and it comes in not inappropriately now in connection with wire conductors. It is to be feared that the excessive inspection made necessary under the Mines Acts has rather tended to a perfunctory kind of operation, and there are stories told of persons at collieries who did not consider the inspections of much importance, but the vital business was the entries in the inspection book, whether the inspections were made or not. A daily inspection of a winding rope, or of a wire conductor, is a mere formality, and so marvellous is the alacrity of men allotted to this work that they can cover the whole of the arrangements in a remarkably short space of time. A winding rope should be thoroughly examined every week, and no better system has ever been introduced than allowing the rope to pass through the hands of the inspector, who is, with a slight amount of unpleasantness, reminded of each broken wire. The inspection of the winding rope can be made by the man at bank, but the examination of wire conductors must be made by the descent of the pit shaft. Defects in wire conductors are very much less likely because they are of larger wire and have little to do; but they should be carefully examined all the same, because a wire projecting from a wire conductor and being caught by the sliding box of the cage may be rich in disaster.

The question will, no doubt, be asked, How many wire conductors should be applied to a cage? It is quite evident that this will be affected by the magnitude of the load and the depth

of the pit shaft. The writer is in favour of an arrangement of three wire conductors in connection with each cage, but he does not say that two conductors may not suffice in some cases, either placed on one side, or one on each side; nor does he say that four conductors, for a heavy load and deep pit shaft, are undesirable; indeed, he thinks they are commendable. But under ordinary circumstances, for ordinary loads and ordinary depths, he has a friendly inclination to the triangular arrangement.

The question of wire conductors to one cage is not difficult to settle, but matters become a good deal more complicated when there are two cages in one pit shaft. The diameters of pit shafts have increased, and may still increase, but even in the largest shafts there can be no great distance between the two cages at the meeting place. There are still some who place the two cages as far apart as is possible, and attach four conductors to each cage, and weight each conductor to its full extent; and years may roll on and no collision take place, because, although both cages are constantly vibrating more or less during the winding, if they are not vibrating towards each other at one particular point they pass without disturbance. But is it fair to the hundreds of thousands of persons who ascend and descend our pit shafts each working day that their immunity from fatal accident should depend on oscillation in the opposite direction at a critical moment? The writer has no hesitation on the subject; he has always held that nothing in the shape of number of conductors, or weight attached to each conductor, can make it impossible for two cages to vibrate much more than the greatest possible clearance between two cages in the largest pit shaft. He prefers, and always has preferred, to proceed on other lines, to recognise the impossibility of preventing this vibration, and, instead of putting cages apart, to bring them closer together and make collision impossible by the adoption of safety conductors between the cages.

Figs. 302 and 303 (*see pages* 510 *and* 511) illustrate arrangements for carrying out this method. In the years gone by these safety conductors, as they are properly called, were not largely used, but it will be no matter for surprise if the present century sees a general adoption. In addition to the three or four conductors that may be attached to each cage, the two safety conductors

are placed between the cages and attached to neither. The advantage in bringing the cages closer together is that the range of vibration is diminished. When first applied, rubbing pieces, attached to the cages, were supposed to be necessary to protect the safety conductors and also the backs of the cages; but, really, it is a question of proper erection of the plant. At one colliery, the shafts of which would be considered deep even in modern times, after several years' work, there were no signs that the safety conductors and the rubbing pieces on the backs of the cages had exercised anything but the merest casual acquaintance.

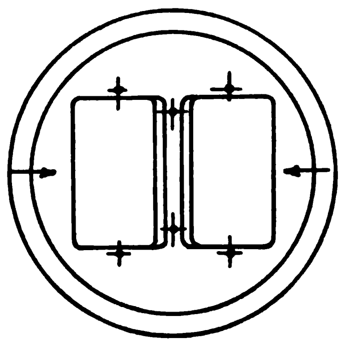


FIG. 302.

SHOWING TWO CONDUCTORS TO EACH CAGE, AND TWO SAFETY CONDUCTORS.

From a consideration of pit-shaft guides we quite naturally pass on to the matter of the cages for which these guides are necessary. In the old days, even after the introduction of cages, they were very primitive structures, weighing a few hundredweights and often carrying only one box. The pit cages of the present day are really important engineering structures, and with the heavy loads which they have to carry—amounting to anything between five and ten tons, and the considerable spans which their contents require, necessitate a well-built arrangement which, under any circumstances, must be of substantial weight, extending to several tons. The material will, of course, be steel, as affording the maximum strength with the minimum weight.

The arrangements in connection with the loading and unloading the cages and securing the contents will have reference elsewhere; the suspension of each cage from the winding

rope may be dealt with here. In the old days the number of suspending chains never exceeded four, and was often less; at the present time we have cages suspended by six and even eight chains. With such a number there must be some means of adjustment, so as to put an equal load upon each chain, and there is probably no better way of accomplishing this than by an adjusting screw in each chain. (*See fig.* 304, *page* 512.) The connection

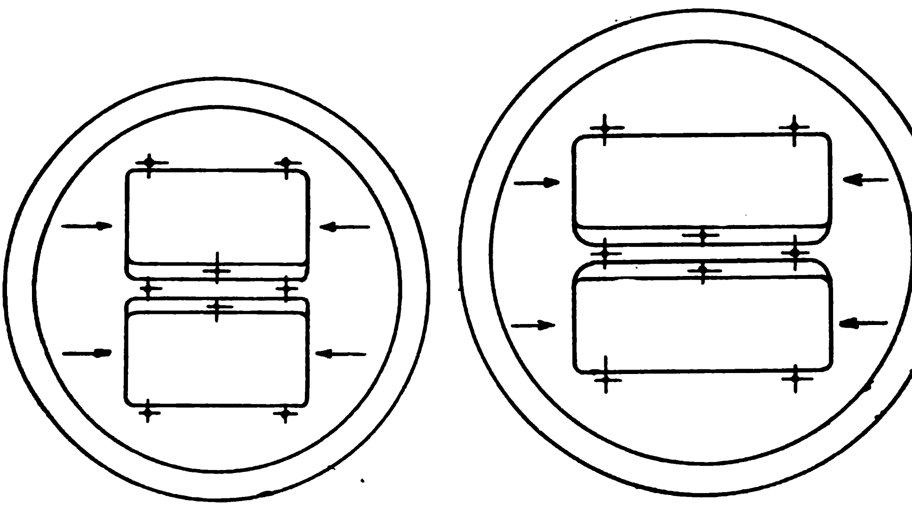


FIG. 303.

SHOWING ARRANGEMENT OF CONDUCTORS, THREE TO EACH CAGE, AND TWO SAFETY CONDUCTORS.

between the winding rope and the cage should certainly not lack in strength, and the short main chain and all the other chains should have an ample margin; a factor of safety of ten, considered necessary in winding ropes, is equally necessary in cage chains. The writer at one time was a good deal attracted by a practical rule for the safe working load on chains—namely, to square the diameter of the material in eighths of an inch, and to strike off the last figure as a decimal, the result giving the safe working load in tons. For example: Suppose a chain of material one inch diameter, $8 \times 8 = 6{\cdot}4$ tons is the safe working. But such a rule reduces the strength of all chains to the same figure, making the weak material appear to be as good as the best material, which is evidently wrong. A better method would be to take the actual ultimate tensile strength of the material, and reckon one-tenth of this result as the safe working load. Just in the

FIG. 804. ADJUSTING SCREW FOR CAGE CHAINS.

same way that we discussed the matter of wire for ropes, and said that every wire should be tested for strength and ductility, and the wires of any one rope should be uniform in strength and ductility, so in cage chains every link of each chain should be made from material of proved uniform strength and ductility; and one link of every chain should be tested to breaking load; in that way we should know that each chain was built up of links quite uniform, and we should know what was the proper safe working load of each chain. It may appear as if the care laid down as being necessary in ropes and chains is excessive, but no one will say so who ever experiences a broken rope or a broken chain. Examination is of course necessary, and indeed compulsory for cage chains, but there is an opinion that no mere inspection will tell us the condition of the chain. It is not absolutely certain that the nature of a good mild steel really changes from fibrous to crystalline in the course of work, although there is a good deal to be said on the side of the argument that the clanging and clashing of chains does tend to brittleness. As the remedy is easy there is no harm in accepting the possibility of such a chain; this remedy is by what we call annealing, and it is a process which has some connection with the tempering of steel. Suppose we wish to give to a piece of steel a certain temper or degree of hardness, we heat to redness, and after plunging into water or oil we allow the material to cool down until it has reached the required temperature, which is made known to us by a particular colour; we then again plunge the material into water or oil and keep it there till practically cold, thus fixing the temperature. In the process of annealing we want no temper at all in the material, and our aim is to take all the hardness out. The chain should be heated to redness, and then allowed to cool down in the

atmosphere; that is what we call annealing, and all cage chains would suffer no harm by undergoing this process say each half-year. To prevent the operation being performed with undue haste spare cage chains should form a part of colliery appliances.

CHAPTER XI.

HEADGEARS AND PIT BANKS.

In the early days, colliery headgears were all made of timber, and although we have passed into the age of steel, and although in new concerns we use timber as little and steel as much as possible, it will be a very long time before colliery headgears of wood are unknown, and in the early years of the twentieth century such erections are very largely in the majority. It is quite fitting that we should lead up to the more modern development by saying something of the early stage; it is always interesting to know something of the more primitive appliances that have preceded modern elaboration.

Figs. 305, 306, and 307 (*see sheet* 12, *between pages* 514 *and* 515) represent in plan and elevation a fairly good type of well-made, neat-looking, and not costly headgear, designed for two ropes, and with the two pulleys side by side and level with each other. The distance between the winding ropes—that is, the centres of the cages working in the pit shaft—enables us to arrive at the width of the headgears at the top. The distance from post to post at the bottom is determined by the necessity to give the feet a firm foundation sufficiently clear of the pit shaft, so as not to crowd the pit top. The width between the backstays at the lower end may very well be such as to give the same inclination outwards that the main posts have. It used to be considered that something like a height of 60 feet from foot of stage to centre of headgear pulleys was sufficient to provide enough clearance between the top of the stage and the centre of the headgear pulleys to enable all the manipulation. That answered well enough when the pit banks did not exceed 20 feet in height, when the cages had not more than two decks each, and when there was not much to provide for above the cage. The state

of things has changed; pit banks are more likely to be 30 feet than 20 feet in height—some detaching mechanism is practically universal in connection with the cage. A fairly good plan is to arrange that the distance from centre to centre of main post and front post shall equal the diameter of the headgear pulley.

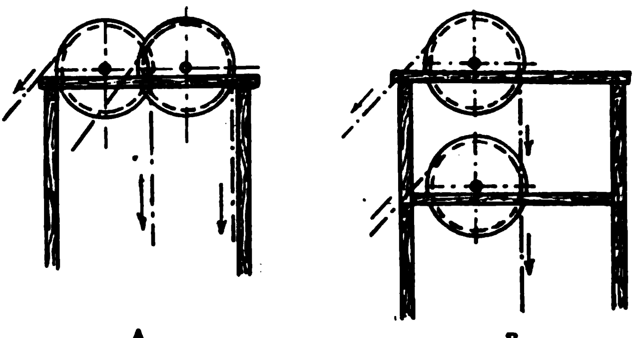


Fig. 308.
Showing Incorrect Headgear Designs.

Wood headgears have been erected, as shown in the outlines given in figs. 308 and 309, which are wrong, as making the entire strain transverse. Wherever possible the pull of the rope should be made to produce compressive strain, and for this purpose the ropes in working should be as nearly as may be parallel to the main uprights and to the main back-

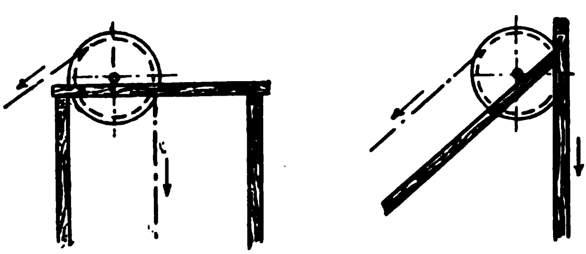
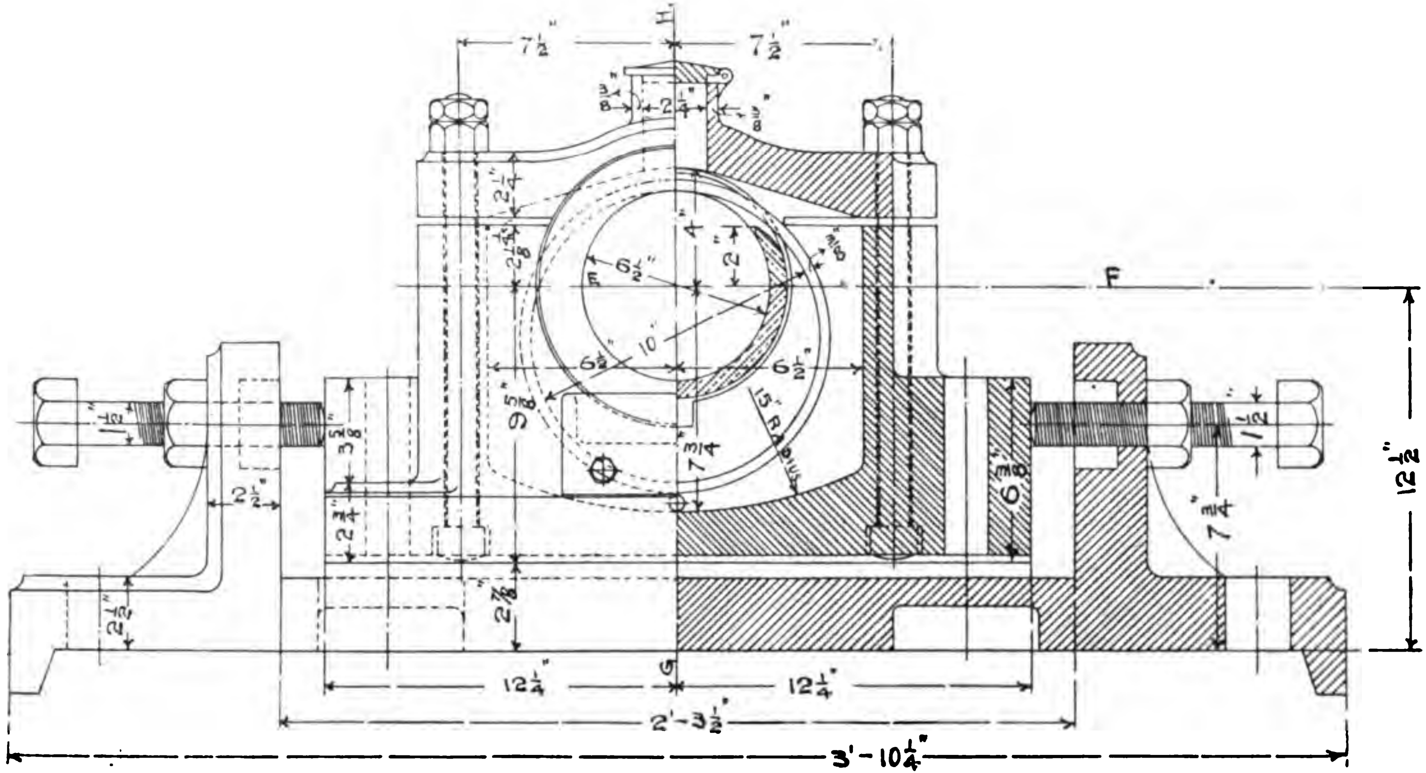


Fig. 309.
Incorrect Headgear Designs.

stays. We have been told that this may be right enough for the main uprights, but that for the line of backstay we should bring in the principle of the parallelogram of forces, and fix the backstays to be a resultant of the line of rope to the drum and the line of rope passing down the pit shaft; to be theoretically consistent the main uprights should be abandoned.



ELEVATION FROM C. D. SECTION AT A. B.

FIG. 810.

ADJUSTABLE HEADGEAR PULLEY PEDESTAL, WITH RING LUBRICATOR. MESSRS. JOHN WOOD & SONS LIMITED, WIGAN.

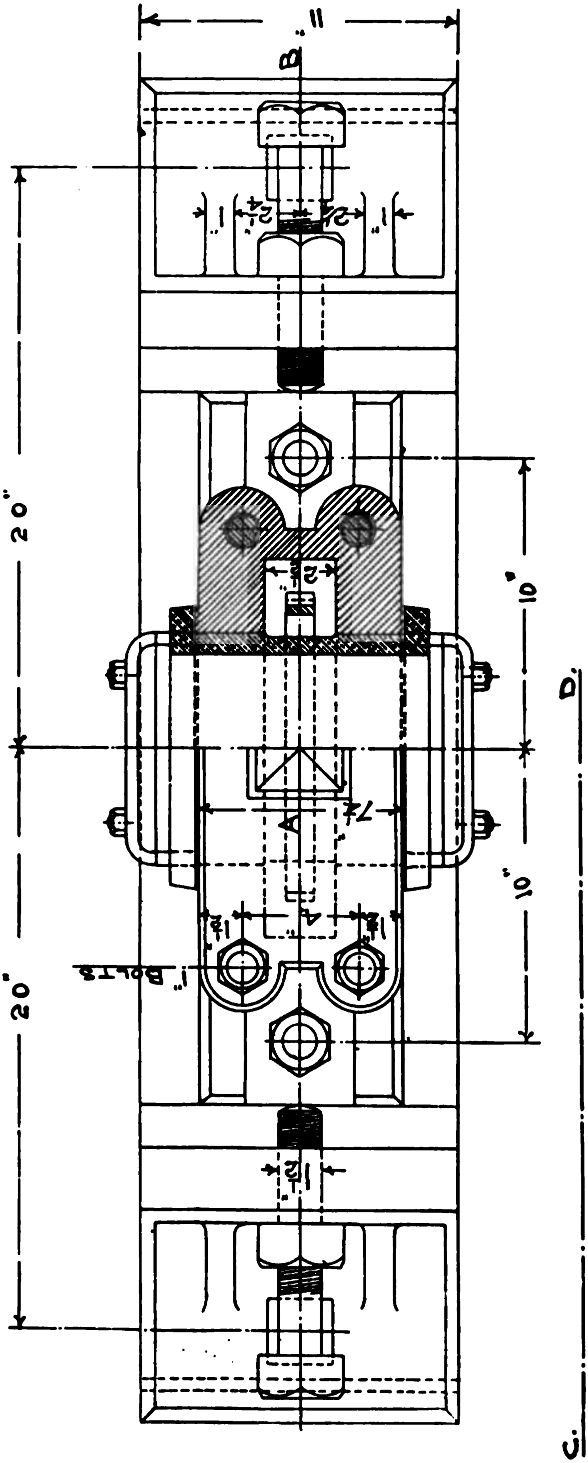


FIG. 311.
PLAN VIEW OF FIG. 310.

That blessed parallelogram of forces, if it is useful for nothing else, enables some of us to show how clever we are, and that in certain circles is worth a good deal. Where we have, as in most cases, an under-rope and an over-rope, they cannot both be in line with the backstay, but the backstay can divide the angle. We do not say that however far the drum may be from the pit shaft the backstay must follow the line of the rope, because to do so would give us an abnormal length of backstay; but we do say that a little less of the parallelogram of forces would be advantageous. Sometimes, perchance, to make the lead of the ropes—that word so dear to ropemakers,

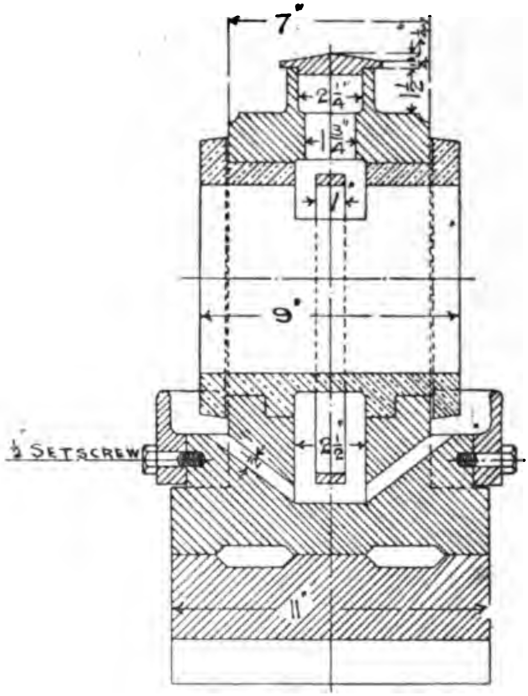


FIG. 312.
CROSS SECTION OF FIG. 310.

"lead"—one headgear pulley is put in advance of the other, or below the other, as shown on fig. 308, **A** and **B** (*see page* 515), but the arrangement answers no good purpose. We are asked by those who make a gospel of "lead" why the under-rope, which works at a sharper angle, does not wear so long as an

over-rope, which works at a greater angle. We suppose it is so, and an explanation can easily be found in the fact that the over-rope is always bending in one direction, whereas the under-rope bends one way on the headgear pulley and the other way on the drum.

In figs. 310, 311 (*see pages* 516 *and* 517), and 312 there is illustrated an arrangement, in connection with headgear pulleys and the pedestal plates on which they rest, of screws enabling a headgear pulley, when occasion requires, to be adjusted. A rope may wear into the rim of the pulley, which wants moving forward to this extent. Often enough headgears subside, and an adjustment of the pulleys enables us to keep the winding ropes in proper line of action. The stability of a headgear is of great importance, and is not always obtainable without a very great deal of trouble. If possible at all, we should excavate to a solid bottom, and there should be good stonework on this brought up to the foot of the main post. If no such firm bottom is obtainable we should form

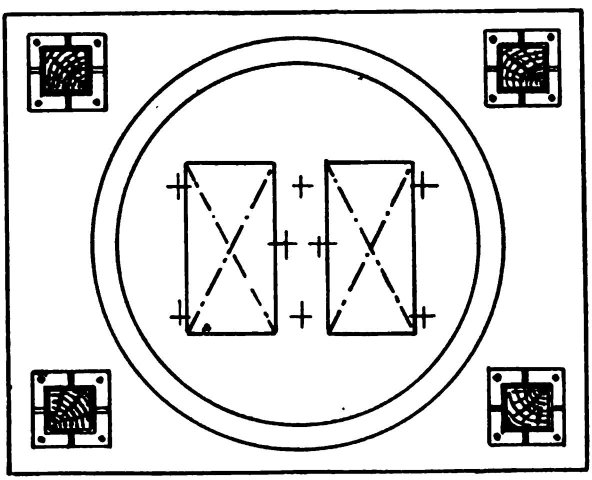


FIG. 313.
PLAN OF FOUNDATION OF HEADGEAR UPRIGHTS.

an artificial foundation of concrete sufficiently broad to give a practically-unyielding foundation. (*See figs.* 313 *and* 314, *page* 520.) In looking back on some early notes we find reference made to the utility of blast-furnace slag for any purposes of foundations, which material, however large the area, made

itself into one mass of rock, and if removal of any portion became requisite blasting had to be resorted to. Indeed, the very heaps themselves, which are neither fair to look upon nor inexpensive to form, manage to constitute themselves into hills well-nigh as firm as the hills of nature. One did hope that the advance of science would have enabled us to avoid such grievous waste, but the progress has not been great, although there is a prospect, in addition to previous uses, of applying it in the manufacture of flags for the pavement of our streets. That all this refuse will find a useful outlet some day is certain, and anything pointing in that direction is a source of pleasure; from small beginnings great results have flowed. The feet of

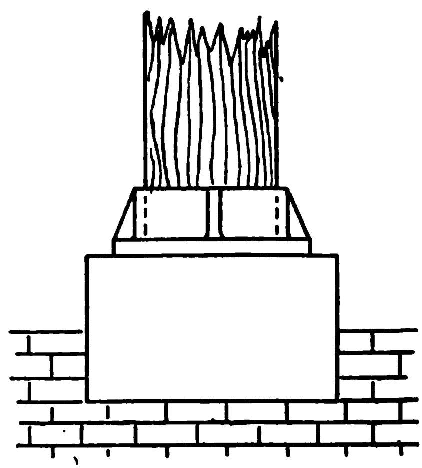


FIG. 314.
FOOT OF HEADGEAR UPRIGHT.

the main posts should fit in metal boxes, and the pillars on which each post rests should stand half a foot or so above the floor level, the object being to prevent water accumulating about the foot of the post. It is important to properly secure the lower end of the backstays, which may be brought down to the floor level; but a preferable arrangement, and one giving much greater stability, is to attach, where possible, the foot of each backstay upon the top of a pillar standing out from the winding-engine house and forming part of that structure. Formerly less strength was requisite in headgear structures, because we were not troubled with the weight of wire conductors

and their attachments, or with the appliances known as detaching hooks. In practically all cases now provision has to be made for these appliances, and this not only affects the size of the uprights but has a very serious influence on the horizontal pieces which span the distance between the main uprights and the front posts. We do not know that very much more is necessary concerning headgears of timber, nor, indeed, with regard to headgears at all.

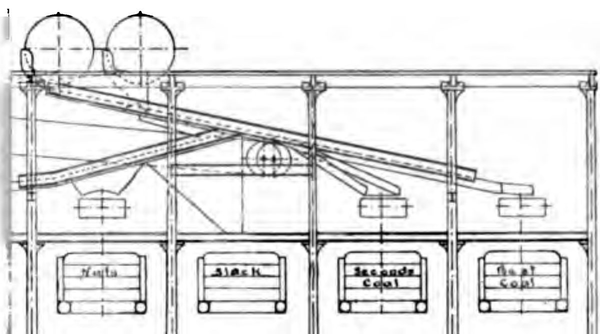
FIG. 317.
AN EXAMPLE OF A COVERED PIT BANK (SILVERWOOD COLLIERY), SHOWING TIPPLERS DRIVEN BY BRITISH THOMPSON-HOUSTON THREE-PHASE MOTORS.

We shall have much to say later on as to the arrangements in steel which, in connection with all new collieries, are preferred to headgears of wood. We have associated in this chapter the subject of pit banks, which can hardly be kept separate from headgears. These important features in colliery arrangements have to unload and load the cages, and, as is mentioned elsewhere, to fulfil all the operations till the wagon is reached which conveys the coal to market.

The early pit banks were very different erections from the present, and our forefathers allowed themselves to be guided a good deal by circumstances. If railways had to be excavated to a considerable depth to suit the general colliery arrangements, then the pit bank to its full height became a solid mound, and was walled in. In other cases it was found convenient to have the ground where the coal was put to stock and the lower landing about level with the tops of the wagons; but the more general custom, and unquestionably the best, was to have the lower landing level with the railways, and to have the pit bank built up upon cast-iron columns, as shown in figs. 315 and 316. (*See sheet* 13, *between pages* 522 *and* 523.) That style of pit bank was made the basis of the modern erections, to which have been added excellent and admirable enclosures covering the entire area of the pit bank, which at the present time is no trifle, and enables the whole of the work upon the coal, from reaching the pit top to passing away in the wagons, being done amidst surroundings of comfort and content. (*See fig.* 317, *page* 521.) It is difficult to realise why it took us so long to appreciate the fact that not only will workpeople work with greater comfort and greater efficiency under cover than exposed to the elements, but that coal cannot be treated except under proper protection and cover.

CATCHES OR KEPS.

Some mention may well be made at this point as to catches or keps identified with cages at the bottom and at the top of the pit shaft. (*See fig.* 318.) These appliances, where used, are for the purpose of supporting the cages when at rest at either extremity of the pit shaft. They can be drawn back out of the way of the winding, and can be put forward so that the framework of the cage, the bottom or some other deck, may rest upon them; they ensure that the cage shall not be able to descend whilst the catches are under it. Opinion has not been universal, either one way or the other, and we believe that all that the law says is—not that they *shall* be applied in the sense of forming part of the colliery mechanism, but that where applied they must be used. It has been said that they are an absolute necessity, and that it is too much to expect a winding engineman to place his cage at the exact point of level without these catches. If


Slack
Seconds Coal
Coal

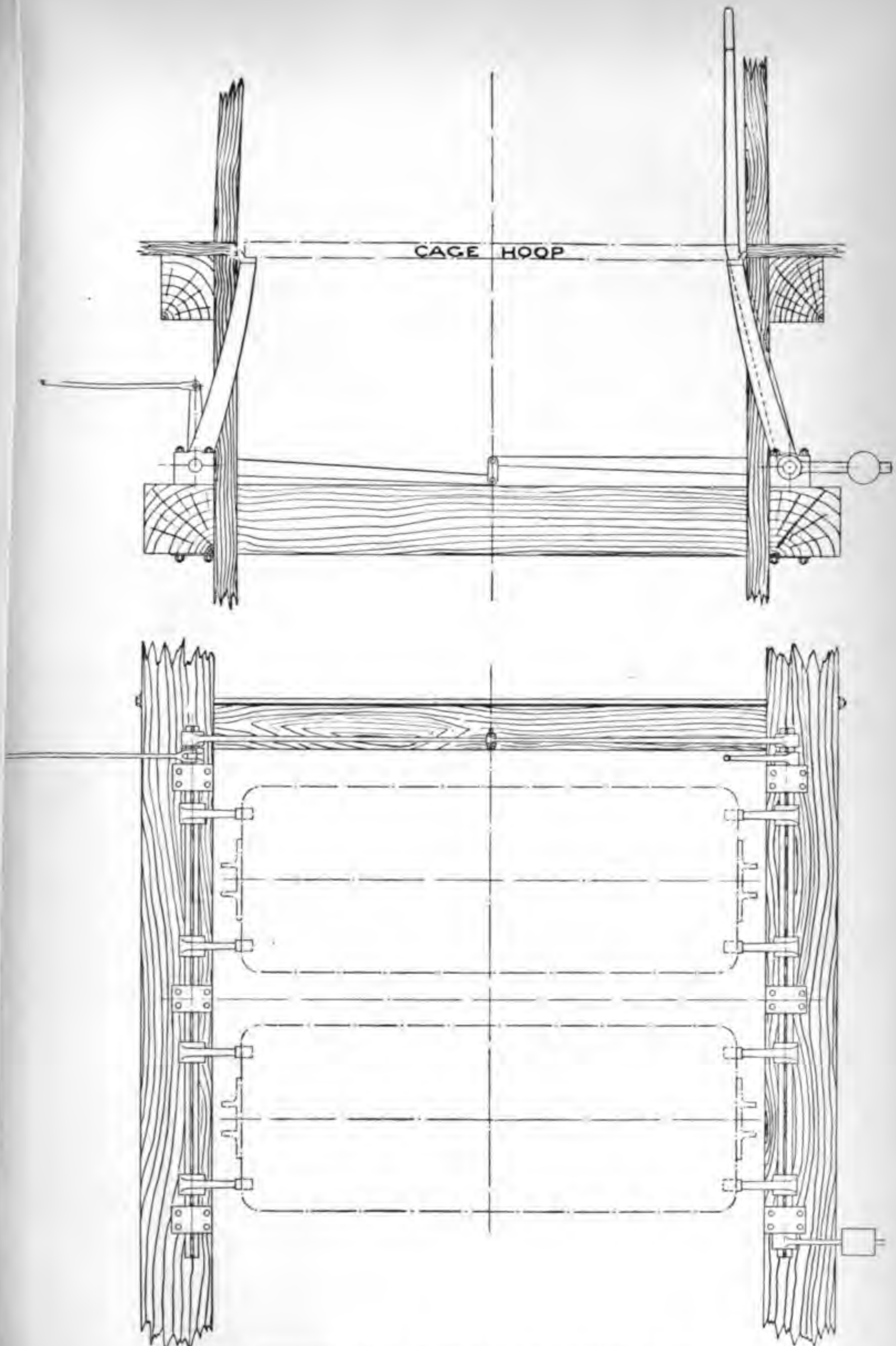


FIG. 318.—SHOWING CAGE KEPS. MESSRS. J. WOOD & SONS LIMITED, WIGAN.

the cage is not placed at the proper point of level, the loading and unloading will not be well done.

It is further said that when workers have to get in or out of the cage their safety requires that these catches should be used. It would be foolish to ignore the soundness of this reasoning, more especially as lives have been lost which would not have been lost had these catches been used. On the other hand, we are told that the use of these catches retards winding operations, and injures the winding rope in the following way: Suppose we put the catches under for the cage to rest upon, the cage, which has been ascending, has to be lowered on to the catches; to remove them, and allow for the descent of the cage, it has to be raised a little, to enable the catches to be withdrawn. The delay to the winding is clear, and the injury to the rope is by the alternate slackening and tightening, whereas without the catches the rope is always tight. There are some catches or keps, which we think bear the name of Stauss, which can be removed without lifting the cage; but is this really an improvement? Whether it is so or not the evidence is in favour of having catches, and of course using them. The better way to minimise the injury to the winding rope by what we call decking is to have as little decking as possible—namely, by doing the whole of the loading and unloading in one operation, whatever the number of decks.

FOWLER'S HYDRAULIC DECKING GEAR.

There is probably, amidst all the plans for accomplishing this purpose, none better than that which the writer saw at work at the Denaby Main Collieries, and which accomplished a very heavy operation in about ten seconds. (*See figs.* 319 *and* 320, *page* 526.) Suppose that there are cages in use, each having three decks; on one side of each cage, on the pit bank, is an arrangement of platforms corresponding with the decks when the cage is at bank. The empty tubs intended for the cage are ready in position, having been elevated by hydraulic power. On the other side is another set of platforms corresponding; hydraulic rams act on the empty boxes, which force the loaded boxes out of the cage on to the corresponding platforms, and the empty boxes charge the cage, which proceeds on its downward journey.

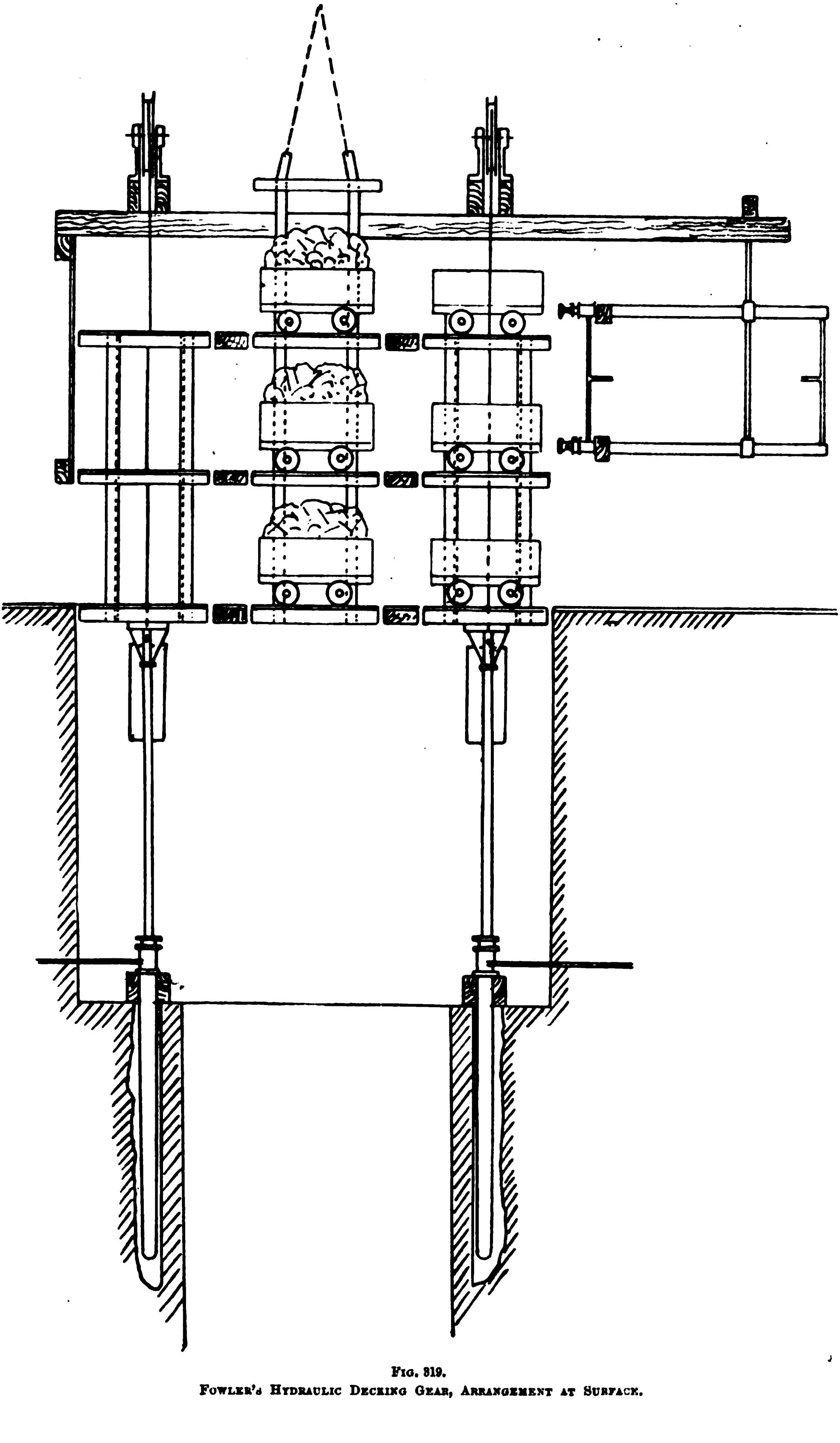


Fig. 319.
Fowler's Hydraulic Decking Gear, Arrangement at Surface.

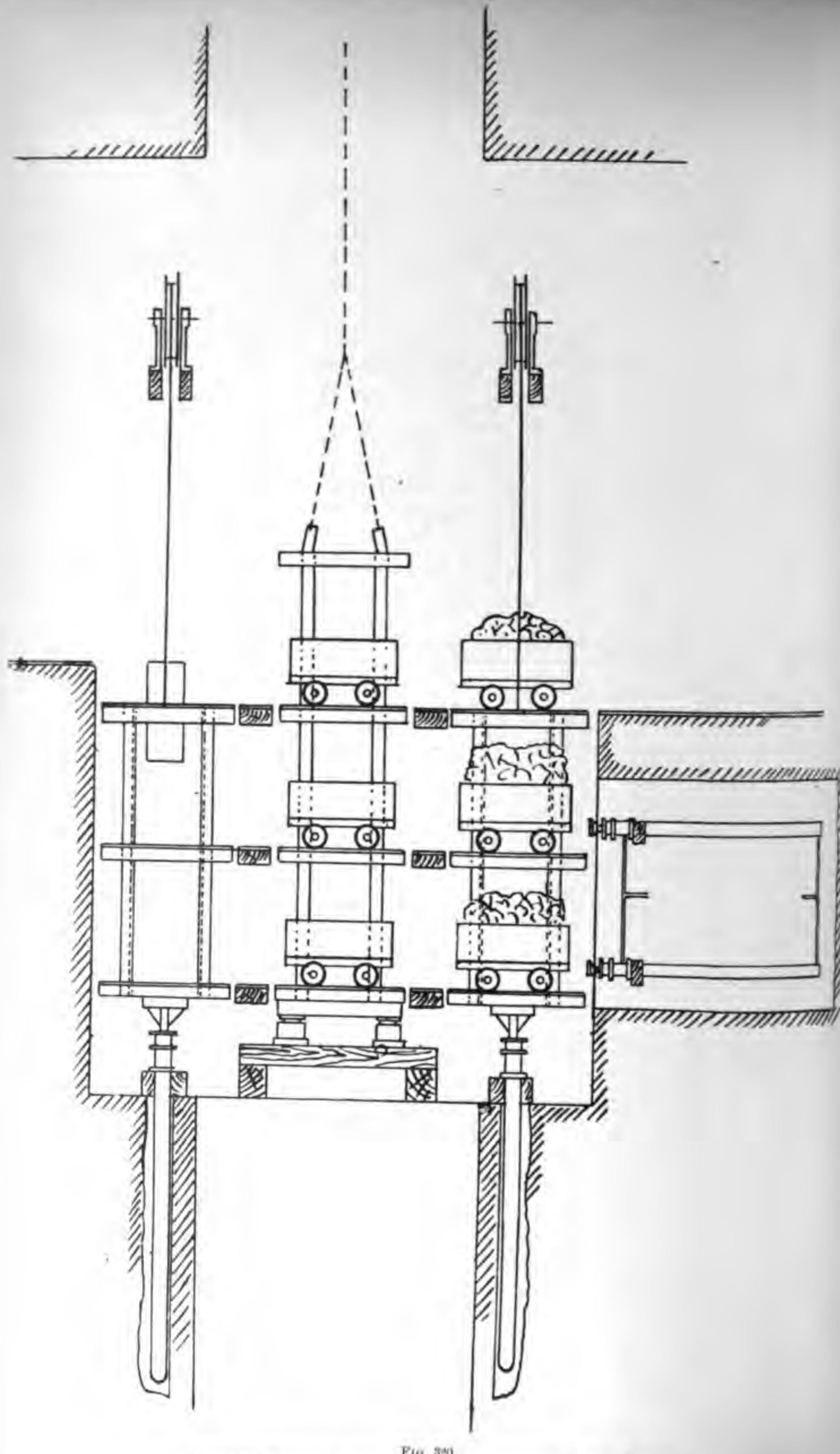
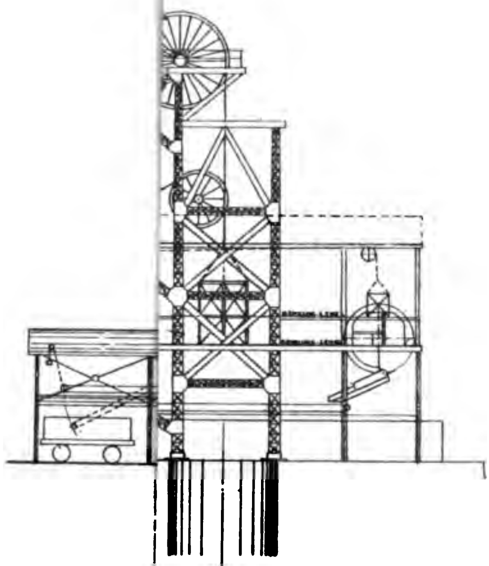
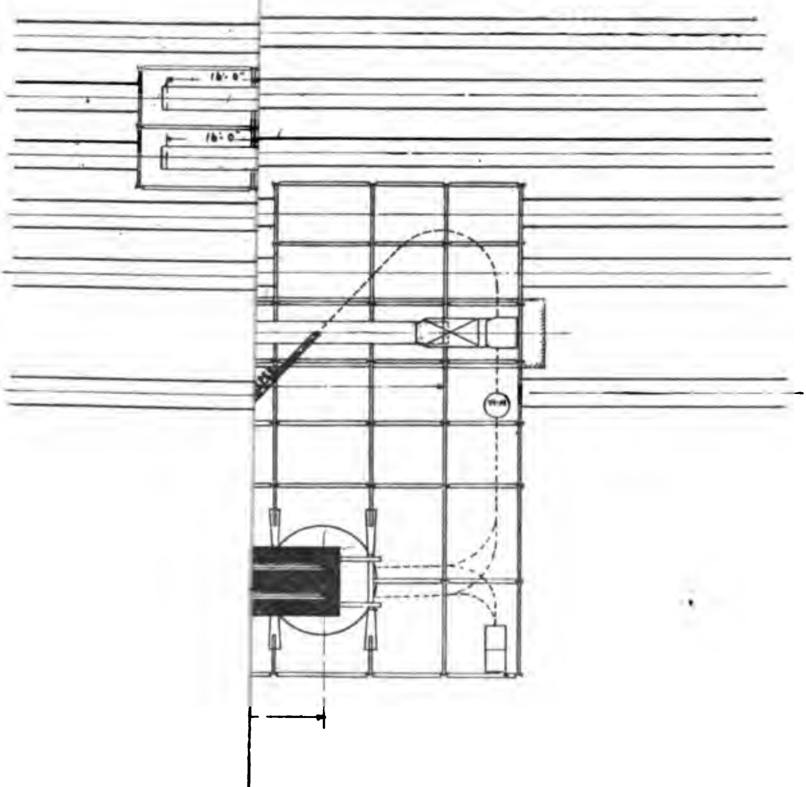


FIG. 320.
FOWLER'S HYDRAULIC DECKING GEAR, ARRANGEMENT AT PIT BOTTOM





PLAN AND ELEVENTS, TIPPLER, AND SCREENS, &c.

During the winding the loaded platforms are lowered and the full boxes pushed out on to the pit bank, and the platforms rise again for another operation. Meanwhile the platforms for empty boxes are lowered, and having received a new consignment of empties, rise to the proper position for the recharging of the cage. The whole thing is performed by hydraulic means, and the expedition is remarkable. This, of course, minimises the possible injury to the winding rope by making one decking suffice for any number of decks. But beyond this there is an important influence. As time goes on we shall want to raise greater quantities of coal in one day at one winding shaft, and whilst it is quite certain that we shall have much greater depths, which will prevent the load increasing at each winding, more time may be occupied in the actual winding, and the working hours are not likely to increase. Half a minute saved in banking would add probably 50 per cent to the number of windings, and it would appear that the solution rests in the application of some such arrangement as has been mentioned.

Where there are only two decks to be dealt with, an excellent plan is that illustrated in the general arrangement shown in fig. 321. (*See sheet* 14, *between pages* 526 *and* 527.) A platform erected above the pit bank level, at a height corresponding with the upper deck of the cage, enables the two decks to be dealt with simultaneously. The loaded wagons from the upper deck gravitate to a balance cage, shown on the right of the shaft. This cage, which is attached to a rope coiling on a pulley, shown on the left of the pit shaft, lowers the loaded tubs and at the same time raises the empty tubs in the cage on the left; the empty tubs also gravitate back to the winding cage. The balance cages, it will be observed, have an unequal amount of vertical movement, in consequence of the inclination of the upper platform, and this is compensated by the pulleys on which the two ropes coil. These pulleys are of different diameters, the one on which the rope from the empty tub cage coils being the larger, thus not only is the difference in the amount of vertical movement provided for, but also the return of the two cages to their proper positions when empty, without the aid of balance weights. It will be understood that the pulley for the empty tub cage, being the larger, the tendency is, when both cages are empty, for the cage on the left to descend

and to raise the cage on the right in readiness for the succeeding windings.

DETACHING HOOKS.

It has been a little difficult to decide where to bring in a reference to detaching hooks, and possibly what has to be said may as well come here as elsewhere, because whenever they act they operate in the headgear. Improvements in colliery operations have been, in some important elements, matters of slow growth. In the early days, when wood conductors were all in all, commendable and ingenious endeavours were made to apply safety cages, which were intended to grip the wood conductors if the winding rope broke, and hold the cage at any point in the pit shaft. For slow winding and wood conductors these safety cages sometimes prevented an accident; but at other times, by refusing to act, they caused accidents. They only could act with advantage when a rope broke, and really we have no patience to consider the possibility of a rope breaking. When wood conductors disappeared, and wire conductors with very high speeds—a mile a minute—came into use, so-called safety cages became obsolete, and other appliances were introduced. The idea was to prevent that much more likely mishap—namely, the drawing of the cage over the headgear pulley. The mechanism to accomplish this was a hook placed between the cage chains and the end of the winding rope. If the cage by any reason was drawn too high, a plate or cylinder at the top of the headgear, which allowed free passage for the rope, but refused a passage to the hook in question, thus severing the association between the cage and the winding rope. The rope passed away over the headgear pulley, and the cage falling back was supported on catches, which might be either in the headgear itself or in the hook itself, or both. That was and is the safety link or detaching hook for preventing the overwinding of a cage.

Many years went on, and very few were applied. The colliery authorities said that the winding enginemen were especially careful because they had to be, and if these appliances were applied they would not feel the same necessity and would not exercise the same care; there are some holders of His Majesty's diploma as colliery managers who say so still. Nearly every mining engineer of eminence thought that no lamp could

touch the Davy or the Stephenson until he had an explosion. Some terrible accidents by overwinding caused fear if not conviction. The argument with regard to the influence on the amount of care of the winding engineman is absurd. If there is no detaching hook the cage may be drawn too high with impunity, and unless the cage goes over the headgear pulley, or the rope breaks and the cage goes down the shaft, no one would be the wiser; but where there is a detaching hook, and the cage is drawn too high, detachment takes place, and there can be no concealment.

The writer has always spoken in the highest admiration of winding enginemen, and the excellent manner in which they discharge duties requiring them every moment to be on the alert. One winding engineman may be called upon to make a thousand windings a week, and it is rather too much to expect from human nature that he shall never start his engines the wrong way, or draw his cage too high. The detaching hook is not a perfect appliance, and there are not many mechanisms of perfection in colliery arrangements. It does not, in a sense, prevent the overwind; it has no influence in the case of a rope breaking, and does not control the descending cage; it is, however, in the opinion of the writer, a useful and necessary appendage to colliery machinery, and whilst of substantial assistance to really good enginemen, by giving them a safeguard and assisting in the expedition with their work, it gives no encouragement to want of care on the part of any winding engineman. There is no scarcity of types of detaching hooks available, many of which are excellent in principle, and manufactured of good material. The writer knows no better class of detaching hook than the Ormerod type, which is made by the Abram Coal Company, who have kindly furnished the accompanying illustrations. (*See fig.* 322 *and figs.* 323, 324, 325, *and* 326, *pages* 530, 531, *and* 532.)

FIG. 322.
THE ORMEROD DETACHING HOOK, AS MADE BY THE ABRAM COAL COMPANY LIMITED.

Fig. 322 shows the hook as in ordinary use. The attachment for the rope is the upper link, and the cage attachment the

lower. The appliance consists of three plates, the outer plates ordinarily carry the load, the inner plate being called into operation only in the event of an overwind. It will be observed that the inner plate projects on one side at the bottom of the arrangement. Fig. 323 shows, in plan and section, the bell-mouthed cylinder secured in the headgear, as illustrated in fig. 324, and through which the winding rope passes.

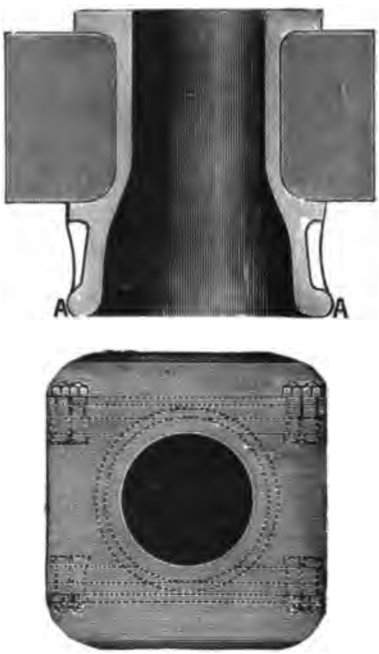


FIG. 323.
THE BELL-MOUTHED CYLINDER.

In the event of an overwind, and the cage being drawn too high in the headgear, the detaching hook is drawn into the bell-mouthed cylinder, and the lower portion being too wide to pass through, the middle plate is forced inwards, causing a corresponding outward movement of the upper part, which results in the pin of the D link being pushed from the recess in which it rests, and allowing it to be withdrawn in the manner shown in fig. 325 (*see page* 532), representing the state of affairs after detachment has taken place. The closing in of the lower portion has the effect of throwing out the two shoulders JJ, which, resting upon the top of the cylinder, support the cage. As, however, there is always a possibility of the cylinder itself being broken or displaced, as the result of an accident, which causes the detachment, it is desirable that supplementary catches be provided in the headgear to support the cage and prevent its falling down the pit.

Fig. 326 (*see page* 532) shows the detaching hook ready to be lowered through the cylinder, preparatory to reconnecting with the rope for the resumption of winding. Bearers or baulks of timber having been placed across the shaft receive the cage, the D link attached to the winding rope is attached to the middle plate in

the manner shown. The cage is now raised a few inches, when the middle plate assumes the position shown in fig. 326 (*see page* 532), which permits of the hook being lowered through the cylinder until the cage rests on the baulks, when the hook can be properly connected.

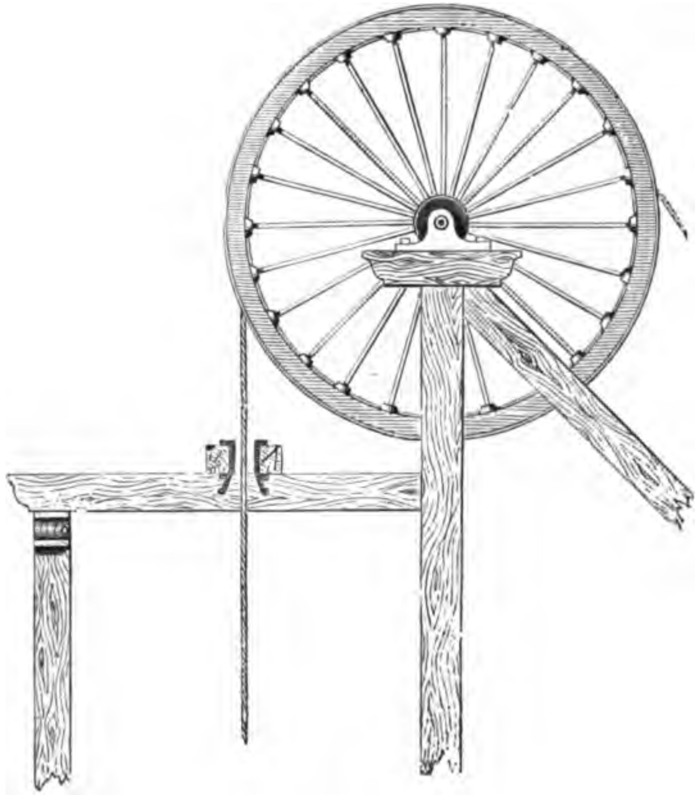


FIG. 324.
SHOWING THE BELL-MOUTHED CYLINDER FIXED IN THE HEADGEAR.

Desirable as these appliances are, it must not be forgotten that they do not, and cannot, *prevent* overwinding, that they afford no protection to the descending cage, and that in the event of an overwind at high speed they cannot possibly prevent the cage crashing into the headgear, possibly destroying the upper portion of that structure, and rendering the cage-supporting appliance useless.

For other safety appliances to *prevent* overwinding, see "Winding Engines."

We are indebted to the enterprising and successful firm of engineers—namely, Messrs. Head, Wrightson & Company Limited, of Teesdale Ironworks, Thornaby-on-Tees—for valuable information relating to colliery headgears, which we very much appreciate, and do not doubt that such appreciation will be shared by our readers.

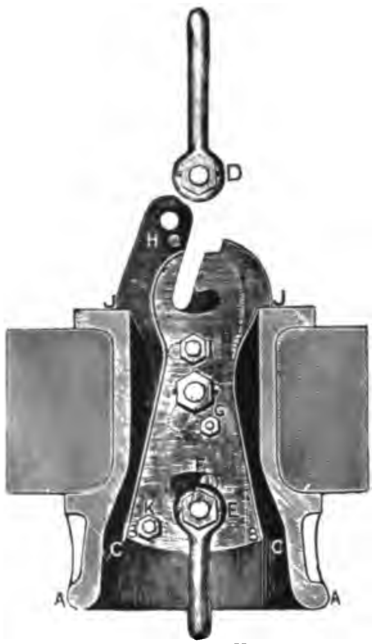


FIG. 325.—SHOWING THE HOOK AFTER DETACHMENT.

FIG. 326.—SHOWING THE HOOK READY TO BE LOWERED AFTER DETACHMENT.

We have introduced Messrs. Head, Wrightson & Company's standard specification of what we may call a joist or plate steel headgear; also a standard specification by the same firm of a lattice steel headgear; and we venture to think that these, as emanating from a firm of high repute and in constant operation, will serve the purpose of our readers better even than some ideal descriptions of our own.

SPECIFICATION
OF
ROLLED STEEL HEADGEAR.

LOADS.—The headgear to be designed for a load of ——* tons on the hoisting rope, and ——* tons on the lowering rope, with a factor of safety of 10.

* To be ascertained for each particular case.

MAIN LEGS AND BACKSTAYS.—To be of steel sections, properly shaped and straightened, firmly braced by means of diagonal tie-rods, where admissible, and T knees.

CROSS GIRDERS.—To consist of steel sections, firmly secured to the main legs and backstays by means of angle cleats and rivets.

SHOES.—Main legs and backstays to be provided with steel plate shoes, firmly riveted to same, and secured to the foundations by means of holding-down bolts.

STEPS.—One of the backstays to be provided with chequered steps and wrought-iron handrail on both sides for easy access to top platform.

PLATFORM.—The platform on top of headgear to be constructed of chequered steel plates firmly secured to the main legs and backstays by means of gussets, and surrounded with wrought-iron handrailing.

SHEAVES.—The winding sheaves to have cast-iron rim and boss, and steel arms, made perfectly true, bored out and keyed to the centre gudgeon.

GUDGEONS.—To be of selected forged scrap, turned all over, with sunk journals having large fillets.

PLUMMER BLOCKS.—To be of cast iron, with gun-metal bottom steps properly machined and fitted, all complete with keeps and bolts, and firmly secured to top platform.

CRAB SHEAVE.—To have cast-iron rim and boss, and steel arms, complete with gudgeon and carriages.

SHAFT FRAMING.—To be constructed of steel sections firmly framed together and braced, secured at the lower end to H girders fixed across the pit shaft.

The top of shaft framing to be provided with steel girders prepared to receive Humble's safety-hook arrangement.

FENCING.—The shaft frame to be fenced on four sides at ground level, and on two sides at banking-out level by means of strong wrought-iron railings and gates.

SLIDING GATES.—To be of light but strong design, arranged to slide on round iron conductors or in channel guides.

KEPS.—To be all complete with forged arms, levers, shafts, and carriages, all properly fitted up on massive kep girders.

MATERIAL.—The headgear to be built of structural steel, having a net tensile strength of 28 to 32 tons per square inch; elastic limit not less than 15 tons; elongation, 26 per cent; bending test, 180 degrees flat on itself without fracture.

WORKMANSHIP.—To be first class throughout, having all abutting pieces properly squared or machined; all rivets, wherever possible, to be machine-driven; all rivet heads concentric with the rivets; field riveting reduced to a minimum; pitch of rivets not to exceed 6 inches, or sixteen times the thinnest plate, nor less than three diameters of the rivets. The rivets used shall be generally $\frac{5}{8}$ inch, $\frac{3}{4}$ inch, $\frac{7}{8}$ inch diameter, rivet holes to be not more than $\frac{1}{16}$ inch larger in diameter than the rivets before closing. The distance between the edge of any piece and the centre of rivet to be not less than $1\frac{1}{4}$ inch, and at least two diameters of rivet wherever practicable.

PAINTING.—All the material before leaving the shops to be thoroughly cleaned from all loose rust and scale, and be given one coat of good oil and red lead paint. Mixture: One gallon raw linseed oil, twenty pounds best quality red lead, and about one quart Japan dryer. All machined parts to be protected with tallow and white lead.

SPECIFICATION
OF
LATTICE STEEL HEADGEAR.

LOADS.—The headgear to be designed for a load of ——* tons on the hoisting rope and ——* tons on the lowering rope, with a factor of safety of 10.

MAIN LEGS AND BACKSTAYS.—To be composed of angles and lattice bars, properly shaped and straightened, and firmly braced together by means of diagonal tie-rods, where admissible, and knees.

CROSS GIRDERS.—To be composed of steel angles and lattice bars, firmly secured to the main legs and backstays by means of angle cleats and rivets.

SHOES.—Main legs and backstays to be provided with steel plate shoes, firmly riveted to same, and secured to the foundations by means of holding-down bolts.

STEPS.—One of the backstays to be provided with chequered steps and handrailing on both sides for easy access to top platform.

PLATFORM.—The platform on top of headgear to be constructed of chequered steel plates, firmly secured to the main legs and backstays by means of gussets, and surrounded with wrought-iron handrailing.

SHEAVES.—The winding sheaves to have cast-iron rim and boss, and steel arms made perfectly true, bored out and keyed to the centre gudgeon.

GUDGEONS.—To be of selected forged scrap, turned all over with sunk journals having large fillets.

PLUMMER BLOCKS.—To be of cast iron with gun-metal bottom steps, properly machined and fitted, all complete with keeps and bolts, and firmly secured to top platform.

CRAB SHEAVE.—To have cast-iron rim and boss, and steel arms complete with gudgeon and carriages.

SHAFT FRAMING.—The top of shaft framing to be provided with steel girders prepared to receive Humble's safety-hook arrangement.

FENCING.—The shaft frame to be fenced on four sides at ground level, and on two sides at banking-out level, by means of strong wrought-iron railings and gates.

SLIDING GATES.—To be of light but strong design, arranged to slide on round iron conductors or in channel guides.

KEPS.—To be all complete with forged arms, levers, shafts, and carriage, all properly fitted up on massive kep girders.

MATERIAL.—The headgear to be built of structural steel, having a net tensile strength of 28 to 32 tons per square inch; elastic limit not less than 15 tons; elongation, 26 per cent; bending test, 180 degrees flat on itself without fracture.

WORKMANSHIP.—To be first class throughout, having all abutting pieces properly squared or machined; all rivets, wherever possible, to be machine driven; all rivet heads concentric with the rivets; field riveting reduced to a minimum; pitch of rivets not to exceed 6 inches, or sixteen times the thinnest plate, nor less than three diameters of the rivets. The rivets used shall be generally $\frac{5}{8}$ inch, $\frac{3}{4}$ inch, $\frac{7}{8}$ inch diameter; rivet holes to be not more than $\frac{1}{16}$ inch larger in diameter than the rivets before closing. The distance between the edge of any piece and the centre of rivet to be not less than $1\frac{1}{4}$ inch, and at least two diameters of rivet wherever practicable.

* To be ascertained for each particular case.

PAINTING.—All the material before leaving the shops to be thoroughly cleaned from all loose rust and scale, and be given one coat of good oil paint. Mixture: One gallon raw linseed oil, twenty pounds best quality red lead, and about one quart of Japan dryer. All machined parts to be protected with tallow and white lead.

COLLIERY WEIGHING MACHINES.

A very necessary detail in the equipment of the colliery for dealing with the coal at bank is the provision of appliances for weighing the coal. For the immediate weighing of the tubs or wagons as they are brought to the surface, a weighing machine is provided near to the mouth of the shaft; indeed, the weighing process is one of the first operations the coal has to go through on its arrival at the surface. This, of course, is a matter between the colliery owner and the miner, and it is to their mutual interest and advantage that the appliance used for the purpose should be convenient and accurate, and that it should be so constructed that the weight of the loaded tub can be ascertained accurately in the least possible time. An operation which, like the weighing of pit tubs, has to be repeated, it may be, two or three thousand times in the course of a working day, is one in which a fraction of a second lost on each occasion amounts to a considerable period of time in the course of the day.

Then there are the weighing appliances for ascertaining the weight of coal loaded into carts and railway wagons, as between the colliery owner and the consumer, and it goes without saying that accuracy and reliability are important features in such appliances.

TONS.	CWT.	QRS.	LB.	W. & T. AVERY LTD., BIRMINGHAM, "SOLE MAKERS"	
19	12	2	14	GROSS	
8	4	1	7	TARE	
· *11*	*8*	*1*	*7*	NETT	
AVERY'S PATENT RECORDING WEIGHBRIDGE.					X 100

FIG. 327.

Messrs. W. & T. Avery Limited, of the Soho Foundry, Birmingham, have furnished particulars of an ingenious arrangement fitted to their weighing appliances, by means of which the weight is automatically impressed with sharp steel type upon slips of card, as represented in fig. 327, except that

the figures are not in ink, but impressed or sunk into the surface of the card. This arrangement not only saves time, but entirely obviates the possibility of an error in weighing or in recording the weight. This, of course, is intended for use in the weighing of carts and railway wagons. It will be understood that an appliance which will accurately determine the weight of wagons up to 20 or 30 tons, and at the same time will permit these wagons to be hauled on and over the weighbridge, call for the highest excellence of workmanship. These machines embody what is known in mechanics as the principle of the "steelyard," which is really an application of the lever. Messrs. Avery

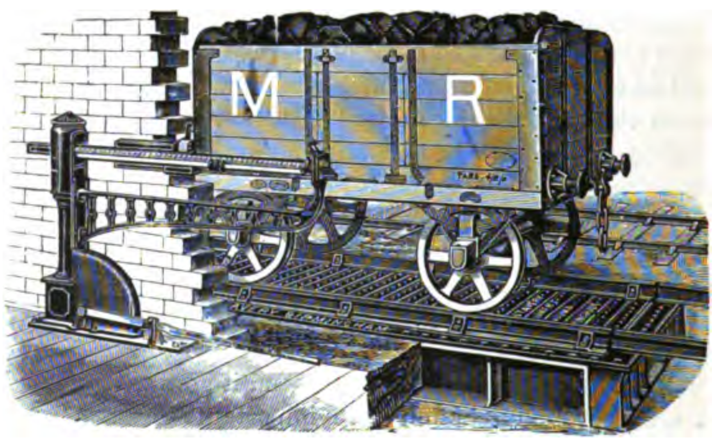


FIG. 328.

construct their machines so as to entirely obviate the use of loose weights. The following extracts from a specification for one of these machines may be of interest:—

SPECIFICATION

OF

SELF-CONTAINED IRON WEIGHBRIDGE FOR RAILWAY TRAFFIC.

(*See fig.* 328.)

To weigh 20 tons. Length of weighbridge 14 feet. Gauge of rails 4 feet 8½ inches.

CONSTRUCTION.—The weighbridge is constructed entirely of iron, and is designed on scientific principles. It is of the improved three-lever type, which allows the platform to swing in the direction in which the traffic moves, and thus prevents undue wear or shock to the knife edges, and prevents all tortional stress.

The underwork is self-contained in a strong cast-iron frame, which can be fixed in position at a small cost, as it dispenses with the expensive brick foundations otherwise required.

The machine is of strong and substantial make throughout.

Frame.—The frame is of cast iron of strong section, the ends being 24 inches deep and the sides 24 inches, with broad flanges at top and bottom, and strong brackets at each end for carrying the rockers from which the main levers are suspended. All the meeting surfaces are accurately machined, and not merely surface-chipped by hand, and securely bolted together, thus producing absolutely true joints, and preventing the possibility of any shifting under stress with consequent variation in weighing.

Loose bearings are provided on the rocker brackets for convenience in replacing.

The top of the frame is roughened by having raised studs cast upon it.

Cast-iron stretchers are fitted between the side frames as a safeguard against the earth pressure causing the frame to spring inwards, which would reduce the necessary clearance between the frame and the weighing platform.

Platform.—The platform is of cast iron of ample thickness. The capacity of the machine is cast on the upper surface, also a chequered pattern to form a foothold for horses.

Girders.—The girders are of steel of ample depth and section, and are capable of sustaining the full load without material deflection; they are provided with cast-iron verges, fitted with hardened steel blocks for bearing on the lever knife edges; the verges are accurately machined and securely bolted to the girders.

Rails.—Steel rails of strong section are securely bolted to the girders to a gauge of 4 feet 8½ inches.

Levers.—The main triangular levers and the transferring lever are of cast iron, fitted with hardened steel knife edges. The connection between the main levers and the transferring lever consists of wrought-iron shackles fitted with hardened steel bearings.

Rockers.—These are of cast iron and are fitted with steel bearing blocks for supporting the fulcra knife edges of main levers. They are suspended so as to allow the platform to swing freely in the direction in which the traffic moves.

Knife Edges and Bearings.—The knife edges and bearings are of specially prepared best welding cast steel, and are accurately shaped to gauges and hardened. They are rigidly fixed in position, the knives being fitted in recesses in the levers and firmly secured by means of screwed wrought-iron shanks and nuts.

In the pit bank weighing machine (*see fig.* 329, *page* 538) the weight of the tub, or rather the weight of the coal in the tub, is indicated by a pointer upon a graduated arc or quadrant. This arc is directly opposite the weighman and check-weighman, and the machine is adjusted so as to give the indication of weight in the shortest possible time. The arc is not graduated from zero upwards, it commences at a predetermined minimum, which is lower than the average weight of coal in the tubs used, and ranges to five hundredweights above this minimum; in other words, the arc is graduated with a range of weights amply covering the

possible variations of weight likely to be met with. The tare, the weight of the tub itself, is permanently provided for in the adjustment of the machine. It may be taken that the weight of the tubs will be practically the same, so that the weight indicated on the arc is at once the net weight of the coal.

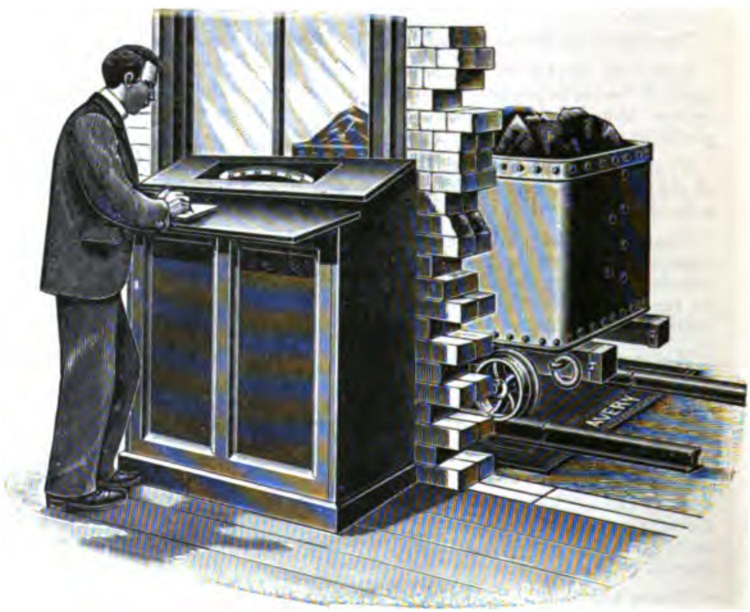


FIG. 329.
AVERY'S PIT BANK WEIGHING MACHINE.

Steel Headgear, Constructed by Messrs. the Pearson & Knowles Coal and Iron Company Limited for the Shelton Steel, Iron, and Coal Company's Deep Pit at Hanley.

Shaft, 940 Yards Deep; Headgear, 72 Feet to Centre of Pulleys, 18 Feet Diameter.

CHAPTER XII.

WINDING ENGINES.

THERE are many divisions of colliery engineering which possess a peculiar importance in connection with the department that they control, and an effort has been made to let each section properly fulfil its importance in this work. There is to most of us, and certainly to the writer, a special fascination in the winding arrangements. The engines, which may well enough develop at a good colliery 1000 horse power, are, as designed and constructed in modern times, splendid pieces of mechanism. They start, and run, and stop, and are manipulated with the greatest ease; they are responsible for the conveyance into the mine and out of the mine of every pound of material, and also for the safe transmission to and fro of every one of our underground workers. If we assume a production of coal of nearly 1,000,000 tons a working day in the United Kingdom, from an average depth of a quarter of a mile, and if we assume that the raising of this coal could operate continuously during eight hours of each working day, we should arrive at an ideal horse power to be expended, as follows: The 1,000,000 tons of coal brought into pounds, and multiplied by the depth in feet, would give us the number of foot pounds of work performed each day, and divided by the number of minutes in the eight-hour working day, and divided by 33,000, would give us something less than 200,000 as the theoretic horse power represented by weight through height. Then, pursuing our ideal assumption by taking two pounds of coal as a fair consumption per hour, we arrive at an amount per working day of something like 1500 tons, being less than a half per cent of the output. It may be accepted that for the generation of steam used in winding engines the consumption of coal is not less than 5 per cent, taking an

average of the appliances of the United Kingdom; the question why there should be such a difference is interesting and important.

The operation of winding is not continuous, and there will hardly be more than one-half of the working day occupied in actual coal winding, the other half being represented chiefly by intervals between the windings. This, however, whilst doubling the required horse power, would not of itself necessarily, or at any rate much, increase the coal consumption; we should simply be working thirty minutes in each hour instead of sixty; but the operation of winding is not one which would be preferred for economy, because it only occupies for each performance a period amounting to less than a minute, and during that remarkably short period the whole of the mechanism, amounting to many tons, has to be started from rest and worked up to perhaps a mile a minute, and at the other end of the journey has to be worked down from possibly a mile a minute to rest. It is all very well to say that in each winding there are three distinct stages—namely, first, speed increasing; second, speed uniform; third, speed decreasing—and that what we should do is to expend the surplus energy of the first stage in the work of the latter stage. It simply cannot be done; but what we can do is to approximate to that condition of things, and to make our arrangements such as will assist in approaching that state of affairs. Our appliances, whilst necessarily powerful, should not be more massive in weight than circumstances compel; in any case, with the winding appliances that must obtain in modern times the weight will be very great. We should also avoid variation in the load during the winding. It is not difficult to understand the peculiar character of the load upon winding engines, and a simple diagram or two would be of assistance.

Fig. 330 (*see page* 542) represents diagrammatically the force developed by a winding engine in various stages of its operation.

The conditions represented are as follow: The shaft is 625 yards deep, and the drum (weighing about 21 tons) is 60 feet in circumference. The horizontal line in the diagram, marked alternately with black and white divisions, represents the depth of the shaft, 1875 feet, and the number of revolutions of the drum rather more than 31.

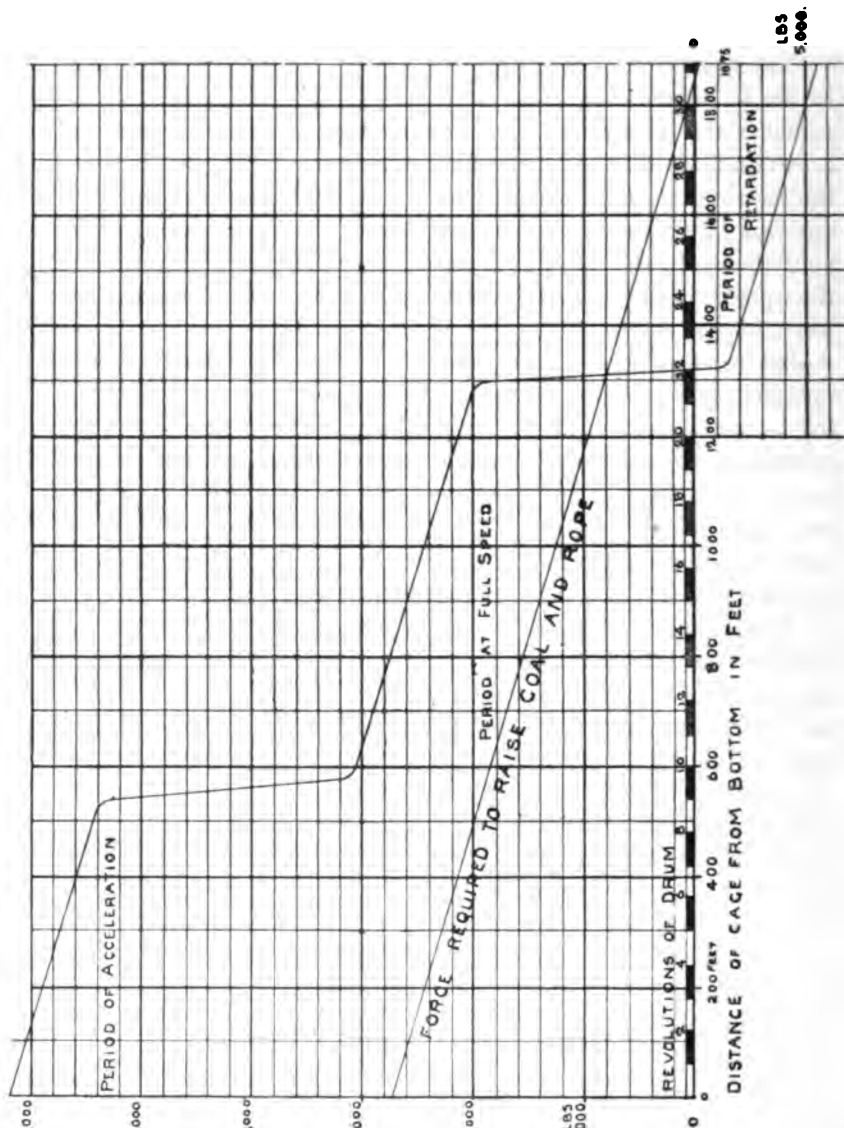


FIG. 380.—DIAGRAM OF EFFORT. SHOWING THE FORCE REQUIRED AT VARIOUS STAGES DURING THE WINDING.

The inertia of the headgear pulleys (weighing about 4 tons) is included in the diagram, together with that of the drum.

	Pounds.
The cage carries six tubs of coal of ten hundredweights' capacity each	6720
Cage and chains	6000
Tubs, six weighing five hundredweights each ...	3360
Rope, eleven pounds per yard × 625	6875

The speed is regarded as being accelerated for fifteen seconds at an average of five feet per second, during which the cage moves through 562·5 feet. At full speed the cage travels 750 feet in ten seconds, whilst the period of retarding has been considered as the acceleration reversed—that is, the cage occupies fifteen seconds in coming to rest, and moves through 562·5 feet.

Weight moved:—

	Pounds.
Inertia of drum and pulleys equal to a weight of ...	33,000
Two ropes, 11 × 625 × 2	13,750
Add weight of ropes from pulleys to engine ...	1,650
Coal	6,720
Cages, two	12,000
Tubs, twelve	6,720
Total weight moved equals	73,840

Force = mass × acceleration, and mass = weight ÷ 32; therefore force equals $\frac{73,840 \times 5}{32}$ = 11,537·5 pounds to create speed.

Force to raise the load:—

	Pounds.
Equals Coal	6,720
Rope	6,875
	13,595
Add force to overcome inertia	11,537
	25,132
Add force to overcome friction, say	6,283
Total force at rope tread equals ...	31,415

Reference to the diagram, fig. 330, will enable the reader

to see how these conditions are represented. At the commencement of a wind the whole effort required is 31,415 pounds, shown by the zig-zag line in the diagram, commencing in the upper left-hand corner above the 30,000 pounds line. The force required merely to raise the load is shown by the straight inclined line commencing on the left at 13,595 pounds. The actual effort at the commencement of a wind, however, is 17,820 pounds (inertia plus friction) in excess of the force to raise the load, which excess is maintained during the period of acceleration.

During the full-speed period the load is made up of the force to raise the load—that is, the coal and rope—plus the frictional resistance, 6283 pounds (assumed on 80 per cent efficiency of engine); at about the tenth revolution of the drum, therefore, the zig-zag line drops to the extent indicated—namely, 6283 pounds in excess of the force to raise the load. During the third period, that of retardation, the effort is a negative quantity, and the load, plus friction, has to be supplemented by the brake, in order to bring the various parts to rest immediately after the completion of the thirty-first revolution of the drum. Thus take the condition of affairs when the ascending cage is 1600 feet from the bottom. The force tending to stop the engine at that particular moment is made up of:—

	Pounds.
Coal, against the engine	6,720
Rope, with the engine, 1600 - 275 = 1325 feet, equals	4,862
	1,858
Add friction	6,283
Force tending to retard	8,141

But the force required to destroy the speed is exactly the same as that applied to produce it, or 11,537 pounds, and 11,537 less 8141 leaves 3396 pounds to be provided by the brakes, as shown in the diagram by the zig-zag line, now below the horizontal O line, showing the retarding effort of the brakes.

Fig. 331 shows the speed of the cages at various periods of the wind.

We must never lose sight of the fact that the only useful work is that represented in the raising of the coals. Suppose we have two ropes working upon a parallel drum, the positive

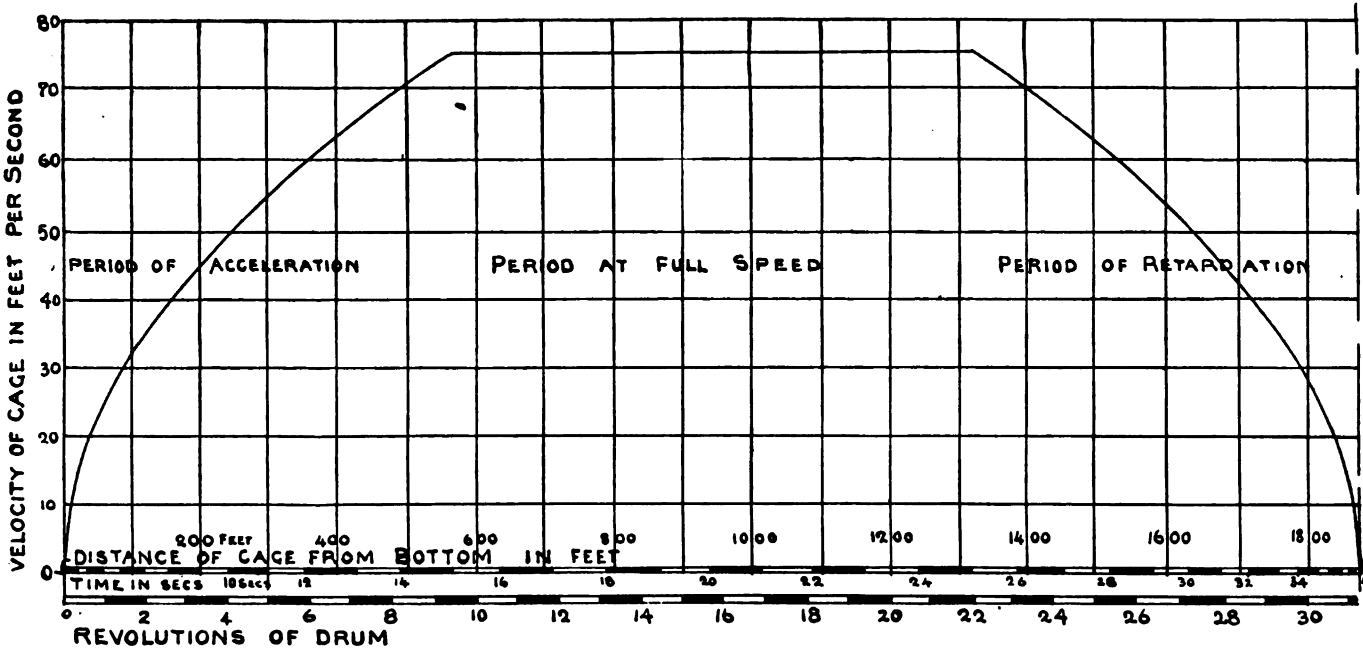


FIG. 331.—DIAGRAM OF SPEED.

It will be seen that for a distance of 562·5 feet the cage is accelerating in speed for 15 seconds, attaining a velocity of 75 feet per second, which continues for a further 10 seconds, when the retarding of the cage commences.

load will be the ascending side, and the negative load will be the descending side; the actual load will be the positive minus the negative. The useful load might well be represented by the weight of the coal raised. What we have to do is to arrange our appliances so that the actual load during the winding will be the weight of the coals, with whatever additions may be inevitable for the frictional resistances, which are considerable in winding operations. Still, when all this has been dealt with—and there are modern collieries at which these ideas are carried out—we should only get to something like double the power and consumption of coal to which we have referred, and this would very likely work out to about 1 per cent of the output. A condition of things of that character would represent a colliery-engineering millennium in the matter of coal consumption, and would give us a saving of not less than 8,000,000 tons a year in coal consumption for winding operations. The figures look startling and are startling, representing several million pounds sterling a year of possible economy. The capital expenditure upon the collieries of the United Kingdom might be taken roughly at one pound for each two tons of coal output per year, or suppose we say a hundred millions sterling altogether. Each two million tons of coal consumption, reckoning value of fuel, wear and tear of boilers, and labour, will represent 1 per cent on this capital; and to be able to effect even that economy from one operation would be a great achievement, and it is well within our power. We have based our assumptions on a condition of things which has been accomplished easily enough in many industries to which steam power is extensively applied—namely, a coal consumption of two pounds per actual horse power per hour. Will any of our readers pronounce it an exaggeration for us to state that, taking all the collieries of the United Kingdom, the coal consumption for winding is not less than ten pounds per horse power per hour? The why and wherefore of this, and the possible remedies, will receive some consideration at our hands before the conclusion of this section.

Let us see at the outset what we want in a colliery winding engine—and in most cases the singular will cover the plural in referring to the subject—because for reasons easily understood and very generally accepted, a winding engine plant in the

great majority of cases comprises two engines working as a pair. There should be no doubt as to the sufficiency of the power; our readers may probably observe that this should apply to all machinery, but in an especial sense it applies to a winding engine, which is the key of a colliery, and there should be the greatest ease in the commencing, the continuing, and the completing of an operation. A winding engine should be perfectly under the control of the attendant, who ought not to have to exercise physical effort to any extent; the starting from any point—and that is where the absolute necessity of a pair comes in—should give not the slightest trouble. It is quite true that in a good arrangement a winding will always commence at the same point, and end at the same point, and the positions of the engine can be fixed accordingly; but there is such an important piece of work as pit shaft examination, and if this is carried out in a proper manner the winding engine may have to stop and start a hundred times during one inspection. The reversal of a winding engine should be a matter of perfect ease, because emergencies do arise under which rapid reversal may be a question of the saving of life; and at the end of each operation the stopping of the winding engine should be a task of the lightest character. Then we come to the question of strength, and although by law and by common-sense we provide apparatus for bringing the workmen to the surface in the event of injury to the regular winding arrangements, it is not frequent to have duplicate winding appliances. Provided that the winding engine is properly designed, properly made, and possessed of sufficient strength with not excessive weight, a winding engine may go on working to advantage during the whole life of a colliery.

The winding engine is made direct acting; that is to say, the winding drum is on the crank shaft, so that we have no intervention of gearing between the crank and the drum. When engines are geared it is for the purpose of increasing the power at the expense of the speed; that is to say, we increase the load, which moves more slowly than the engine. We do not want that arrangement in winding, because at the average colliery in any country, with the usual depths, the pistons of the engine will not, as a rule, travel at a fourth of the speed tha obtains with the cage; therefore we evidently want no gearing

to reduce the speed. Then it may be said that gearing can be applied to increase the speed, and winding is an operation in which increased speed is a requirement. But gearing is not a perfect arrangement, and it is very questionable as to its advantages for winding. At any rate we do not apply it, and the increase of speed between the piston and the cage is accomplished by the large size of the winding drum in proportion to the length of the stroke of the engine. It may seem somewhat odd to state now that in some mining districts of the world some winding engines have gearing, but the explanation is that the winding is performed from mines of depths which are not considerable, and therefore the load is more important than the speed.

At one time there was not a consensus of opinion in favour of the horizontal type of winding engine, and the horizontal is not universal now, but it holds the field. The old vertical winding engine was a good deal used, and was high in favour. It occupied less ground space; it placed the headgear pulleys more in line with the drum, which was mistakenly supposed to be an advantage; and it gave a more perfect action to the pistons, because they moved up and down on vertical lines. Generally the engineman was on the same floor as formed the top of the cylinder, and the drum was above him; sometimes the engineman was placed on the floor of the winding drum, with the engine beneath him. The writer did not find any benefits arising from the vertical winding engine of years ago, and without saying for one moment that the vertical winding engine is wrong in principle, he has always had a preference for the horizontal class. It is a good thing for a winding engineman to be able to see his machinery, and the horizontal class affords better facilities for this than the vertical.

Examples will be given later on to show how we arrive at the relative proportions of the power and the resistance. The power is the average effective pressure of steam in pounds per square inch operating on the area in square inches of the piston; the resistance is the load at the end of the winding rope, which may be simply the weight of coals, or a good deal in addition to the weight of coals. Whatever it is, the resistance has to be multiplied by the average speed of the rope, or, what is the same thing, the average circumference of the winding drum.

The power has to be multiplied by the average speed of the piston, or, what amounts to the same thing, twice the length of the stroke of the piston. Evidently the latter must be in excess of the former, and this is provided for by due allowances. It is not so easy as it seems to convince some who really ought to know better that the resistance should be multiplied by the circumference of the drum.

A set of examiners for colliery managers' certificates, who had given a question bearing on the subject in the examination paper, could not agree. One brilliant member of the triumvirate insisted—and the awkward juryman always exercises much power—that the proper method of calculation was to multiply the power by the length of the crank, and the resistance by the radius of the drum. The decision arrived at was, that if the question was answered in this way it should be considered right, and if the question was answered in the other way it should be considered right also, and so the consciences of all were satisfied. It would be a pleasure to the writer to immortalise this Admirable Crichton, but the gentle shepherd shall spare him. How is the work of a revolution arrived at? Surely by taking the distance that the piston of the engine travels during a revolution, which will be a distance equal to twice the diameter of the crank circle. How is the work expended in a revolution of the drum arrived at? Surely by taking the distance which the load will travel during a revolution, and which is certainly not twice the diameter of the drum, but the circumference of the drum.

We mentioned a little way back the almost universal practice of a winding engine being constituted of a pair; fig. 332 (*see page* 550) is intended to illustrate our remarks at this point. In all steam engines—that is to say, the ordinary reciprocating steam engine with crank motion—there are four principal points in each revolution—namely, two dead centres—at each of which the crank is in line with the piston and cylinder, and two midway points, with which we have nothing to do at the present moment. When the crank is at either of the dead centres an engine is powerless, and will not start from such a point; by having two engines working as a pair we place them so that their cranks are at right angles, and when the crank of one engine is on a dead centre the crank of the other engine is on full throw.

That arrangement annihilates dead centres, enables a winding engine to start without the slightest difficulty from any point, and that is why a winding engine arrangement comprises a pair of engines.

There will be opportunities later of making some reference to winding engines which show a substantial advance in many respects over their predecessors; but no harm will de done in making some abbreviated reference to the orthodox type of of winding engines which practically reigned supreme a quarter of a century ago. The arrangement was horizontal, and the diameter of each cylinder was equal to half

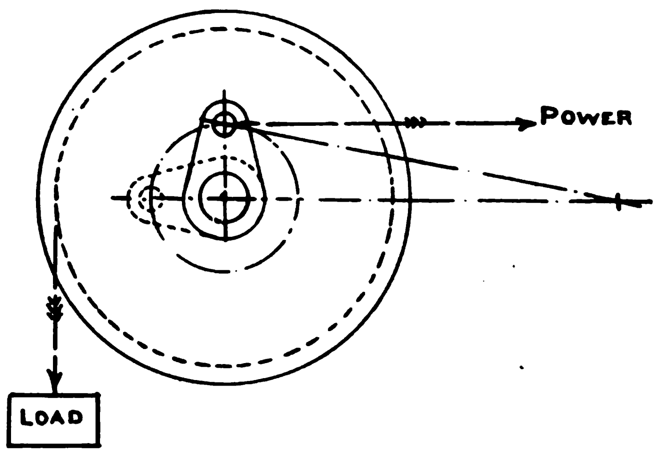


FIG. 332.

TO ILLUSTRATE THE PRINCIPLE OF THE COUPLED WINDING ENGINE. ONE CRANK IS SHOWN IN A POWERLESS POSITION.

the length of the stroke; there were two cylinders exactly similar, the engine working high pressure. The available pressure of steam at the engine was 60 pounds on the sqaure inch, and was very fair as matters went then. We have improved upon that, and there is now no really good reason why we should not endeavour to apply steam of very high pressure; our boilers are equal to it; the strengths of the parts of the engine are also equal to it. The higher the pressure the greater the power an engine of a certain size will exercise, and in the use of high-pressure steam lies the opportunities for economy. The winding engine rested upon a foundation structure of cast iron, that material being the cheapest and answering

every necessary purpose, and so constituted as to afford the needful strength in support, and also forming a gigantic washer to cover the engine pillars. (*See fig.* 333.) The practice was to plane the underside of these bedplates, so as to give a solid bearing on the pillars. The cylinders were of cast iron, and that material fulfils all needful requirements. The interior can be bored to an admirable surface, and there is no difficulty as to strength to resist the pressure. It is considered good

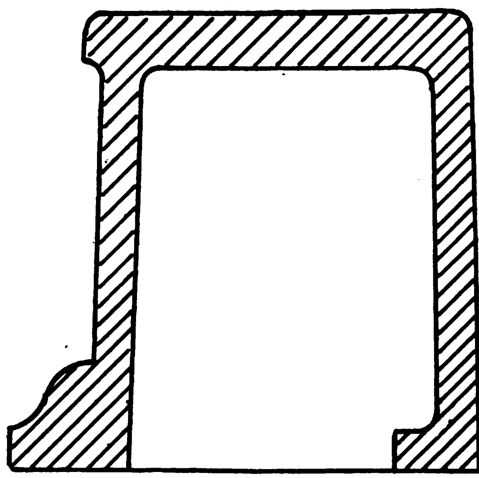
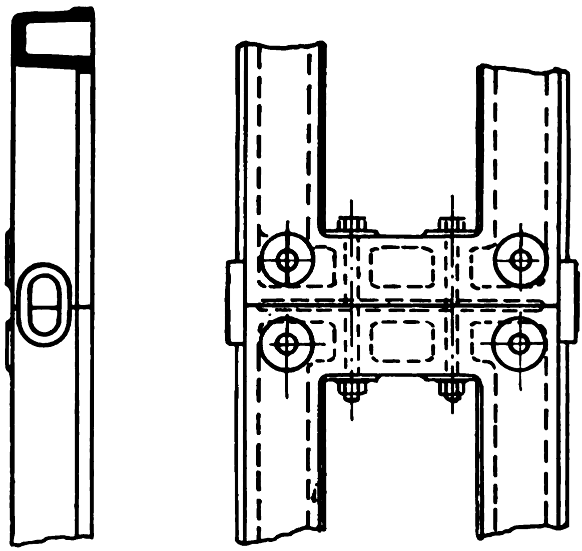


FIG. 333.
SECTION OF BEDPLATE FOR WINDING ENGINE.

practice to bore a cylinder in that position in which it has to work, and in calculating the thickness of metal required provision should be made for re-boring. (*See fig.* 334, *page* 553.)

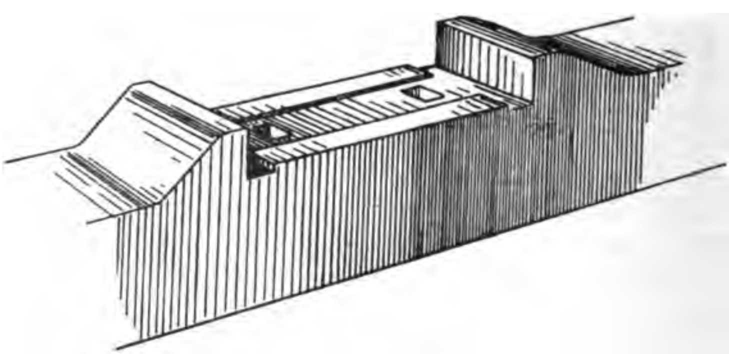
A good cylinder arrangement in those days was one with Cornish valves, the idea being to make the engine easy to handle. There are many good Cornish valve winding engines still, but having a separate valve box, two at each end for each cylinder; they are hardly economic. The cylinder was made just a little longer than the length covered by each stroke of the piston, but not much, because clearance capacity to excess is wasteful. Each end of each cylinder was made somewhat larger than the body, the object being two-fold—namely, to enable the piston at each end of the stroke to free itself, and avoid the formation of an objectionable ridge; also to be a help

in changing the rings of the piston. (*See fig.* 335.) The form of the cylinder cover depended on the form of the piston, and a very usual practice was to have the cylinder cover



SHOWING JOINT IN BEDPLATE.

so made that a flange fitted the flange of the cylinder, and a dish portion of the cover entered the end of the cylinder and was often tight. (*See fig.* 335.) Except to fit the piston



SHOWING JOGGLES ON BEDPLATE FOR THE PEDESTALS.

and diminish clearance capacity this dish portion of the cylinder cover answered no purpose, because the joint should depend upon the flange connection with the flange of the cylinder.

The writer had a very curious experience—in trying to remove the cylinder cover, the dish portion had become quite tight in the cylinder; the ring forming the flange came away and left the dish in the cylinder. Assuming that all the pressure within

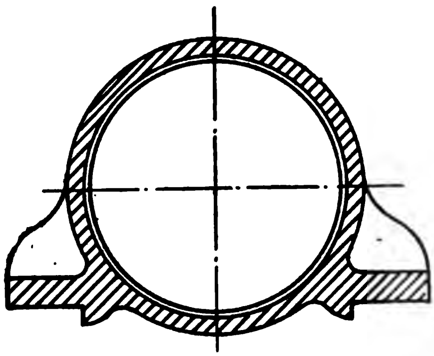


FIG. 884.
SHOWING SECTION OF CYLINDER WITH FEET OR BRACKETS TO REST ON THE BEDPLATE.

the cylinder acted outwards, the ring was put back and bolted in. A day or two later it was found that the dish portion was gradually being drawn into the cylinder, showing that occasionally,

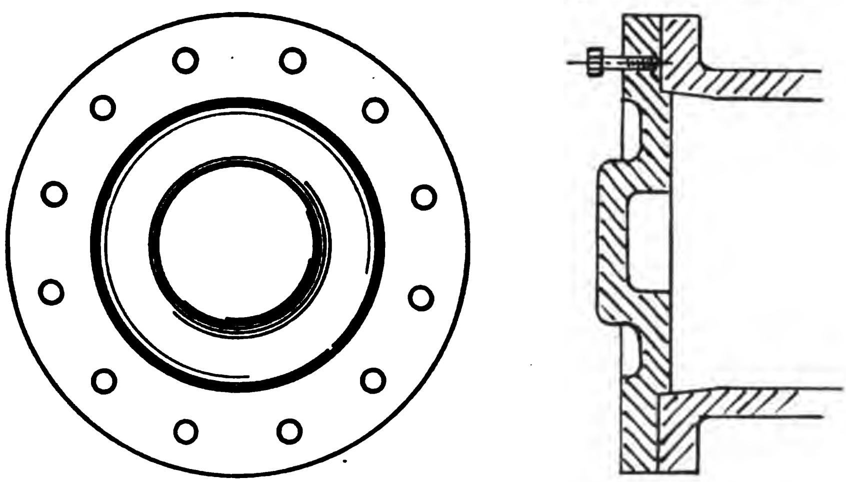


FIG. 885.
SHOWING CYLINDER END AND COVER.

and at some periods of the working of the engine, there was a vacuum, however slight, in the cylinder. A lesson gathered from this accident was, that in the cylinder cover of large engines, a

good plan is to have three or four screws placed round the flange of the cover, to enable a gradual easing off. (*See fig.* 335.) A cylinder cover gets very fast at times, and wedges, which are the first things thought of, are a clumsy means of getting over the tightness. The number of bolts in a cylinder cover will depend on the diameter of the cylinder and the maximum pressure possible to prevail. The resisting area of a bolt is, of course, the area at the bottom of the thread, and there ought

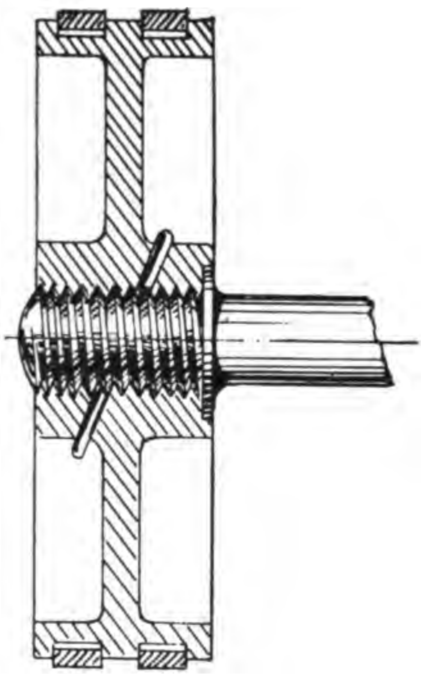


FIG. 336.
SECTION OF PISTON.

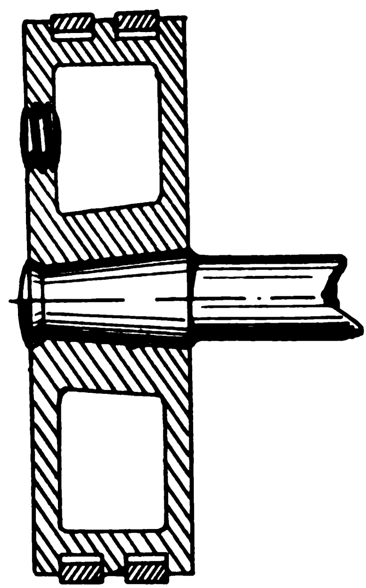


FIG. 337.
SECTION OF PISTON.

to be no difficulty in the use of a material equal to a safe working load of two tons on the square inch. The type of steam piston which was in use before so many patent pistons came into the market, and which is a fairly popular piston still, is shown in figs. 336 and 337. What we want in a steam-engine piston is a piece of machinery that will exactly fit the true bore of the cylinder, and the very best piston we could have would be a solid block exactly the diameter without that

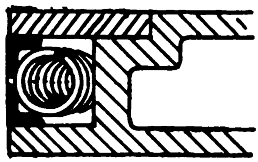


FIG. 338.
PISTON WITH RINGS AND COILED SPIRAL SPRING.
(THE LANCASTER PISTON.)

the cylinder is within. But such an arrangement would only be perfect for a short time; the piston would tend to wear slightly less, and the cylinder would tend to wear slightly larger. All the piston arrangements are intended to make provision whereby there shall be a certain amount of spring provided in some way to take up this wear. (*See fig.* 338.)

The arrangement shown in figs. 336 and 337 is as simple as it is possible to contrive. The piston itself is turned perfectly round, and slightly less than the cylinder. In the rim of the piston there are grooves. In these grooves are placed cast-iron piston rings; there may be one in a groove, there may be two in a groove. A ring of cast iron is turned outside and inside, the inside being such that the ring when made will be clear of the bottom of the groove, and the outside is about one-thirtieth larger in diameter

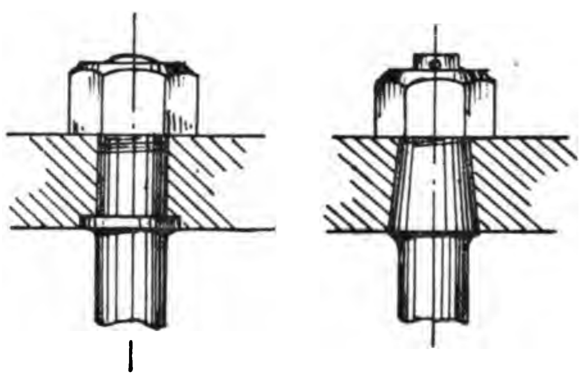


FIG. 339.
SHOWING METHODS OF ATTACHING PISTONS TO THE PISTON RODS.

than the cylinder. This ring, which may be a foot long, is cut in the lathe into rings of the width required. Each ring is made too large for the cylinder, a piece is cut out, and the two ends arranged for springing together. Each ring is put back into the lathe and skimmed to the exact bore of the cylinder. Very good results have been obtained, and the width and depth of each ring being proportionate to the size of the cylinder, one inch square answers for a piston 30 inches diameter, and we may add or

deduct one-eighth of an inch each way for each 6 inches diameter, greater or less. Figs. 336, 337, and 339 (*see pages* 554 *and* 555) represent methods of securing the piston to the piston rod. In horizontal winding engines with no cylinders except high-pressure, the piston rod goes through the cylinder cover at the front end only for attachment to the crank motion, and provision has to be made in the cylinder cover.

At one time it was very common to have tail piston rods passing through the back cylinder cover; the idea was that, especially in large cylinders, say 36 inches diameter, a bearing behind the engine was necessary in the back cover, and behind the cover, to enable the piston to work to advantage in the cylinder. Then came an inclination to dispense with these tail piston rods altogether, and some remarkable results were announced—namely, that the removal of these tail rods was equal to increasing the effective pressure on the piston several pounds, and that no injurious influence was experienced. By removing these rods the effective area behind the piston was increased by an amount equal to the area of the rod. Suppose the piston was 36 inches diameter, and the piston rod 6 inches, the proportions of the areas would be as 1 to 36, and as the piston worked both ways, whilst the altered area only operated one way, the effective addition was 1 in 72, so that the increase considered in that way would hardly be equal to one pound of effective pressure per square inch. No doubt the benefit was greater than this, because any resistance of the tail piston rod would cease. The writer's opinion was that these tail rods could well enough be dispensed with, that the piston would work well enough without; that it was impossible in practice to adjust the bearings of these tail rods to avoid some resistance; and that although the saving was not so great as claimed, there could easily enough be a saving, and the inconvenience of tail piston rods with back guides was got rid of.

Figs. 340, 341, and 342 (*see sheet* 15, *between pages* 556 *and* 557) show the general arrangement of a winding engine cylinder fitted with Cornish valves having a ball-and-socket arrangement on the valve spindle. The object of the ball-and-socket joint is to ensure that the valve will sit down truly on its double seating; unless some adjustability is provided the valve will not sit right, and therefore is not tight. These valves

must, of course, be very carefully adjusted, because unless the distance from face to face of seating exactly coincides with the distance from face to face of valve, the valve cannot close. To guard against the possibility of the high temperature affecting its accuracy, both the valve and its seating should be of brass, and should be cast from the same melting of the same metal. There are some excellent features in this Cornish

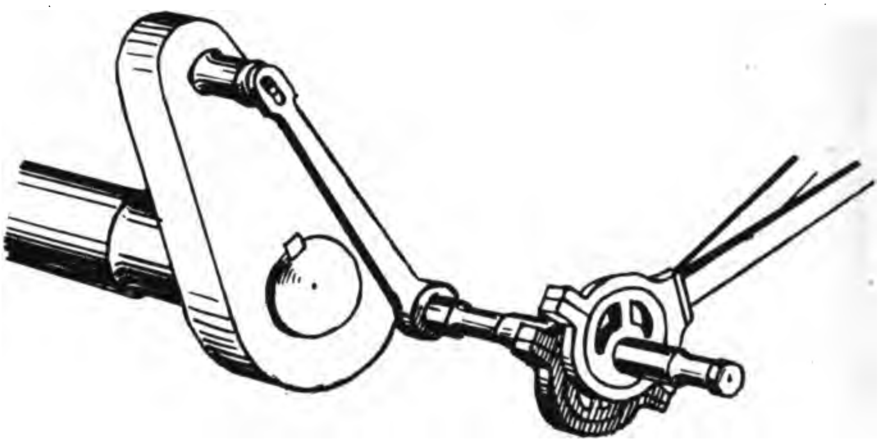


FIG. 343.
SHOWING ARRANGEMENT OF ECCENTRICS.

valve. It is not perfect in its equilibrium, but it is approximately an equilibrium valve, therefore easily opened and easily closed. The opening, being circumferential, is large for a small lift, and having two seatings even this large opening is doubled. Cornish valves have been popular for winding engines as affording easy action and large orifices. The valve motion which worked the valves was the ordinary link motion, the chief feature being the eccentrics, which, although doing good service in their day, could never be considered even approximately perfect mechanisms, on account of the enormous frictional resistance which they set up. So great is the friction of an eccentric, that whilst we can convert the motion of an eccentric into reciprocating movement, we cannot reverse the operation. Sometimes these eccentrics were placed on the crank shaft, which was not desirable, because they occupied too much space and were cumbersome and inconvenient. Fig. 343 represents one method of applying the eccentrics other than on the crank

shaft. In the ordinary high-pressure winding engine there was nothing peculiar in the crosshead or slide bars, nor even in the connecting rods, the ends of which are shown on figs. 344, 345, and 346.

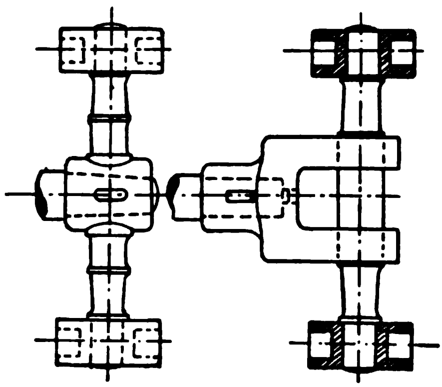


Fig. 344.
Piston Rod Ends and Crossheads.

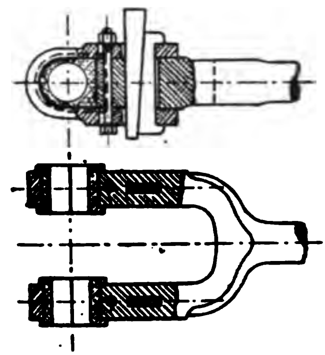


Fig. 345.
Connecting Rod Ends.

The crank of a winding engine (*see figs.* 347, 348, *and* 348A) is a very important part of the machinery; the whole of the power passes through it; the crank itself must be strong, and its securing to the crank shaft and the securing of the crank pin to the crank must leave nothing to be desired. A

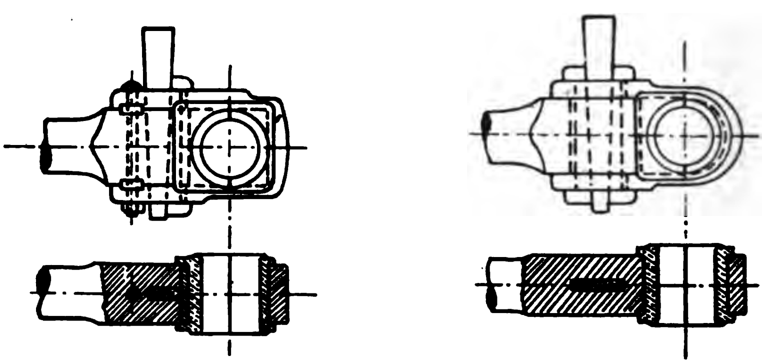


Fig. 346.—Connecting Rod Ends.

plain crank is best, and there is admirable steel at our disposal. Probably the best method of securing the crank on the crank shaft is to make the hole a shade less than the shaft, and force the crank on by hydraulic pressure. The same remark applies

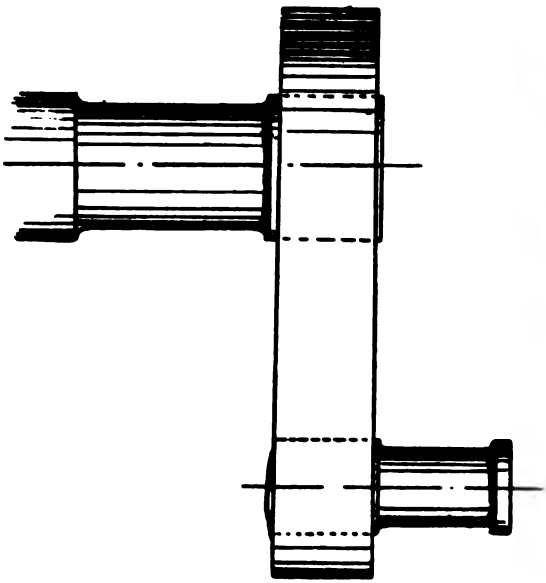


Fig. 347.—The Crank.

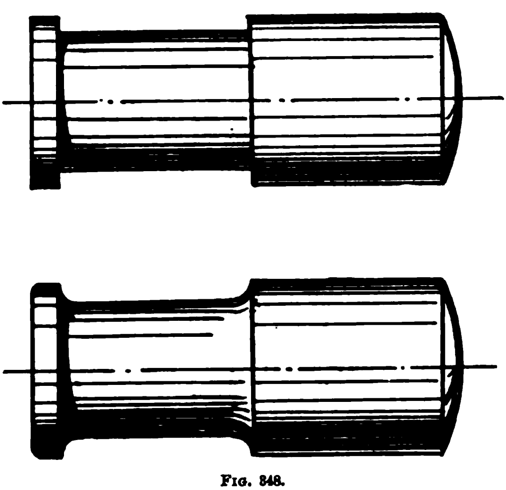


Fig. 348.

The Crank Pin, Showing Correct and Incorrect Forms of Journals. The Upper One is Incorrect.

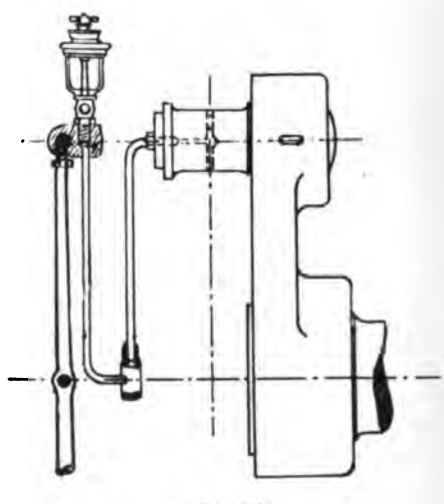


Fig. 348a.

Arrangement for Lubrication of the Crank Pin.

to the crank pin. The pedestals of the crank shaft of winding engines in some cases were made straight up (*see fig.* 349, *and figs.* 350 *and* 351, *pages* 562 *and* 563), but usually angle pedestals were applied. In winding engines the vertical load on the bearings of the crank shaft is the weight of the shaft itself and the drum, together with the cranks and part of the connecting rods. The pull upon the winding ropes is represented by the loads on the ropes, and acts along the line of the ropes leading to the headgear. There are therefore two forces, differing in amount, and acting at an angle substantially greater than a right angle. The object of the angle pedestal is to throw the resultant of these two forces on to the solid bearing. Fig. 352 (*see page* 564) shows the principle of the angle pedestal. The arguments would appear to be all in favour of these angle pedestals, and especially as the vertical load diminishes and the pull on the ropes increases. Each winding engine should have a good throttle valve of the Cornish type, and the same precautions for enabling it to be tight are necessary as were referred to in connection with the valves attached to the cylinders. (*See fig.* 353, *page* 565.) What we call a winding-engine indicator is an appliance which indicates the position of both cages throughout the winding, and there is probably nothing better than a miniature representation of a winding, the two cages on a small scale shown imitating on a small scale the action of the two cages in the pit shaft. The engineman, within whose sight this arrangement is fixed, would see at once if he started the wrong way, and would know to a nicety where each cage in the pit shaft was.

The writer once heard a mining engineer, afterwards an examiner for colliery managers' certificates, tell one of His Majesty's judges that a winding engine was at least as well without a winding indicator as with. He said that so long as they were not universal an engineman who came from a colliery where they were not in use to a colliery where they were in use was likely to make a mistake. There really are some wonderful geniuses amongst the mining engineers of the Old Country and other countries, but the mining engineer who holds such sentiments as these should certainly not be left in the enjoyment of unfettered liberty; he is more likely than not to do himself an injury.

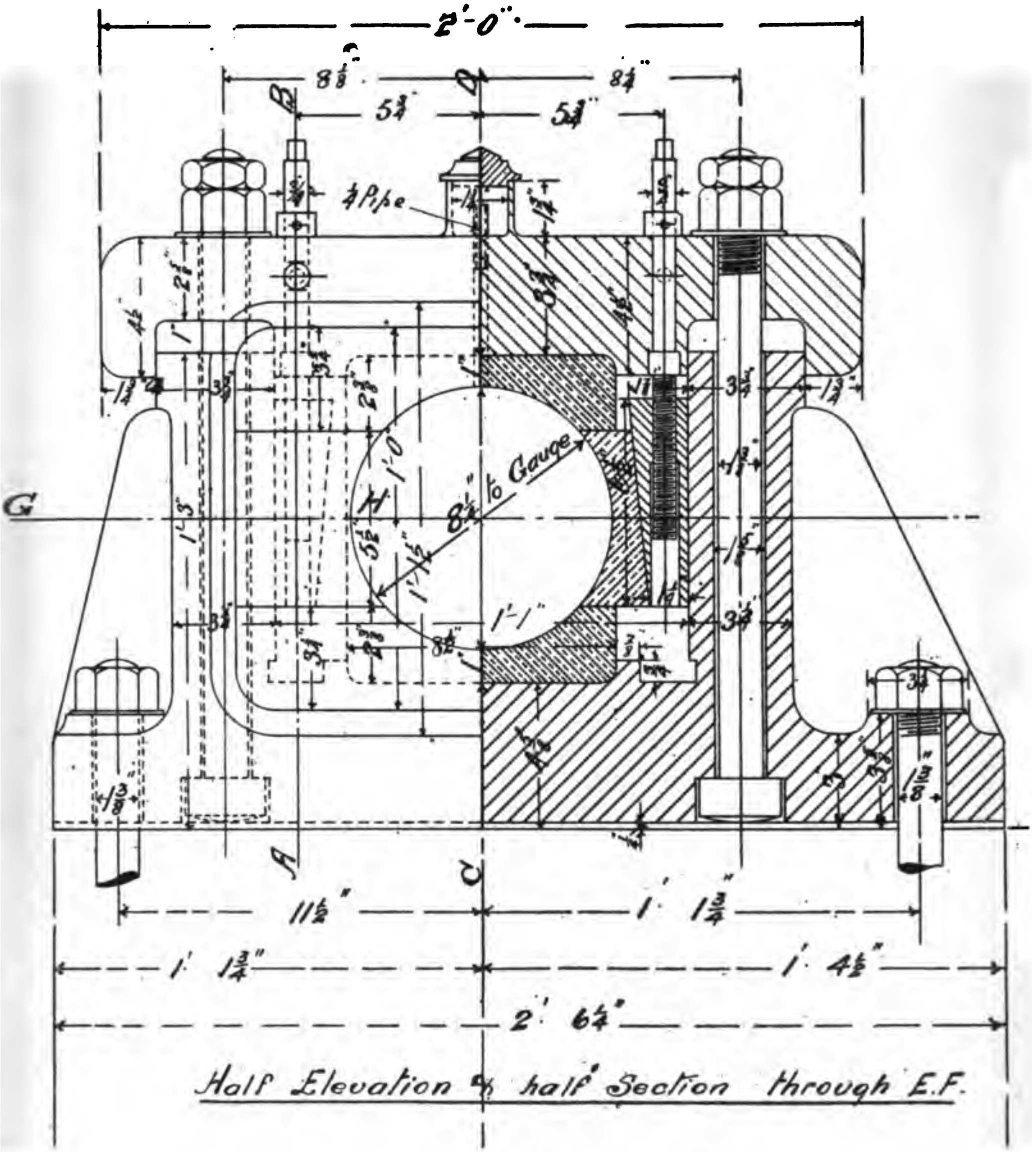


Fig. 349.

Crank Shaft Pedestal, with Adjustable Brasses.

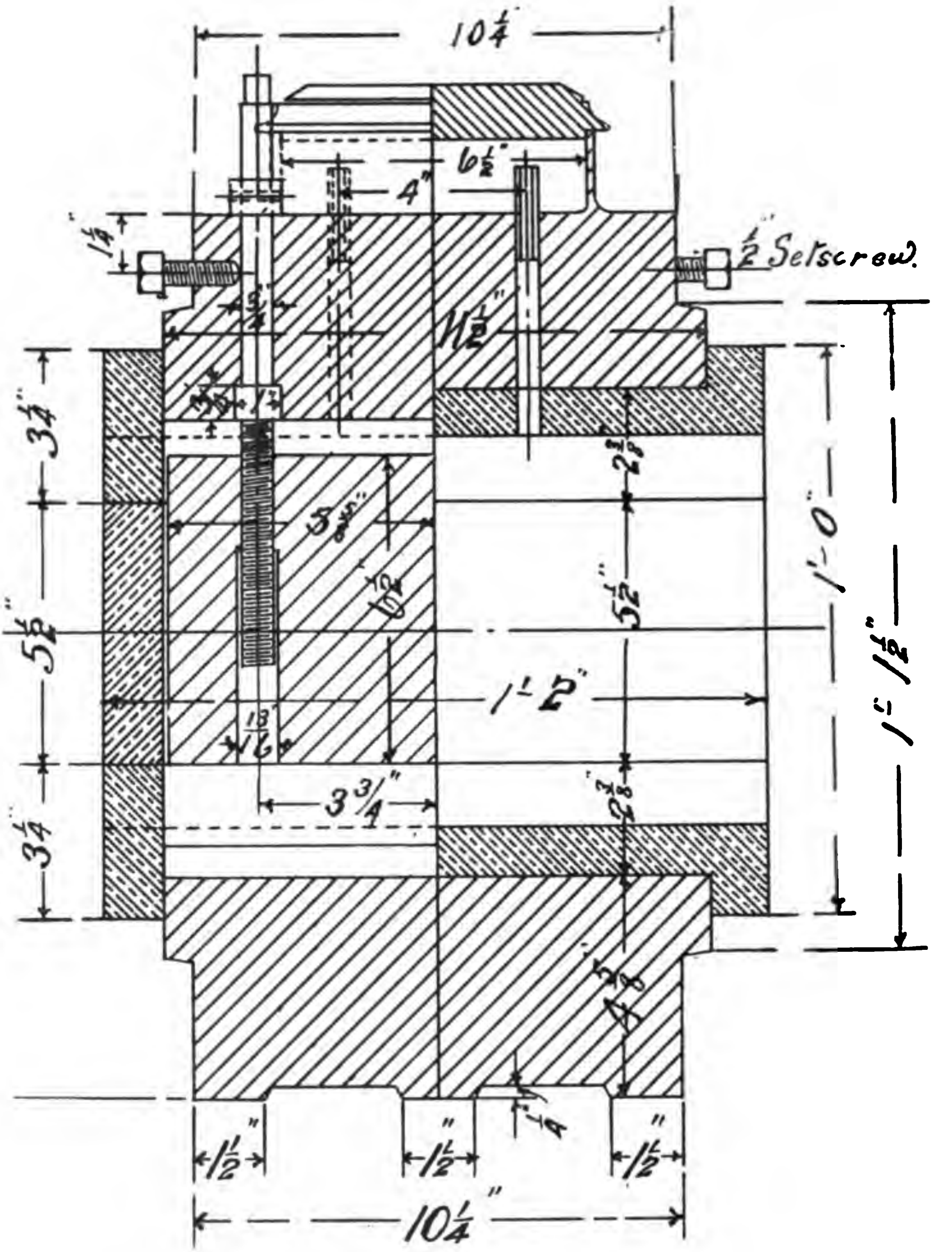


Fig. 350.
Section at A B and at C D. (See Fig. 349.)

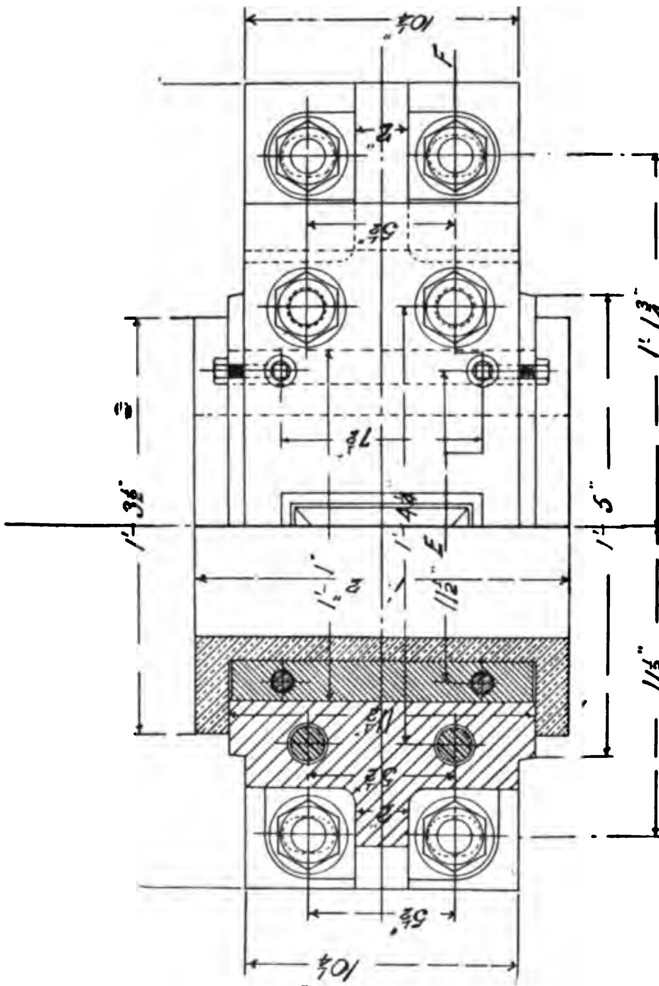


FIG. 851.
PLAN OF FIG. 849. HALF SECTION ON LINE G H.

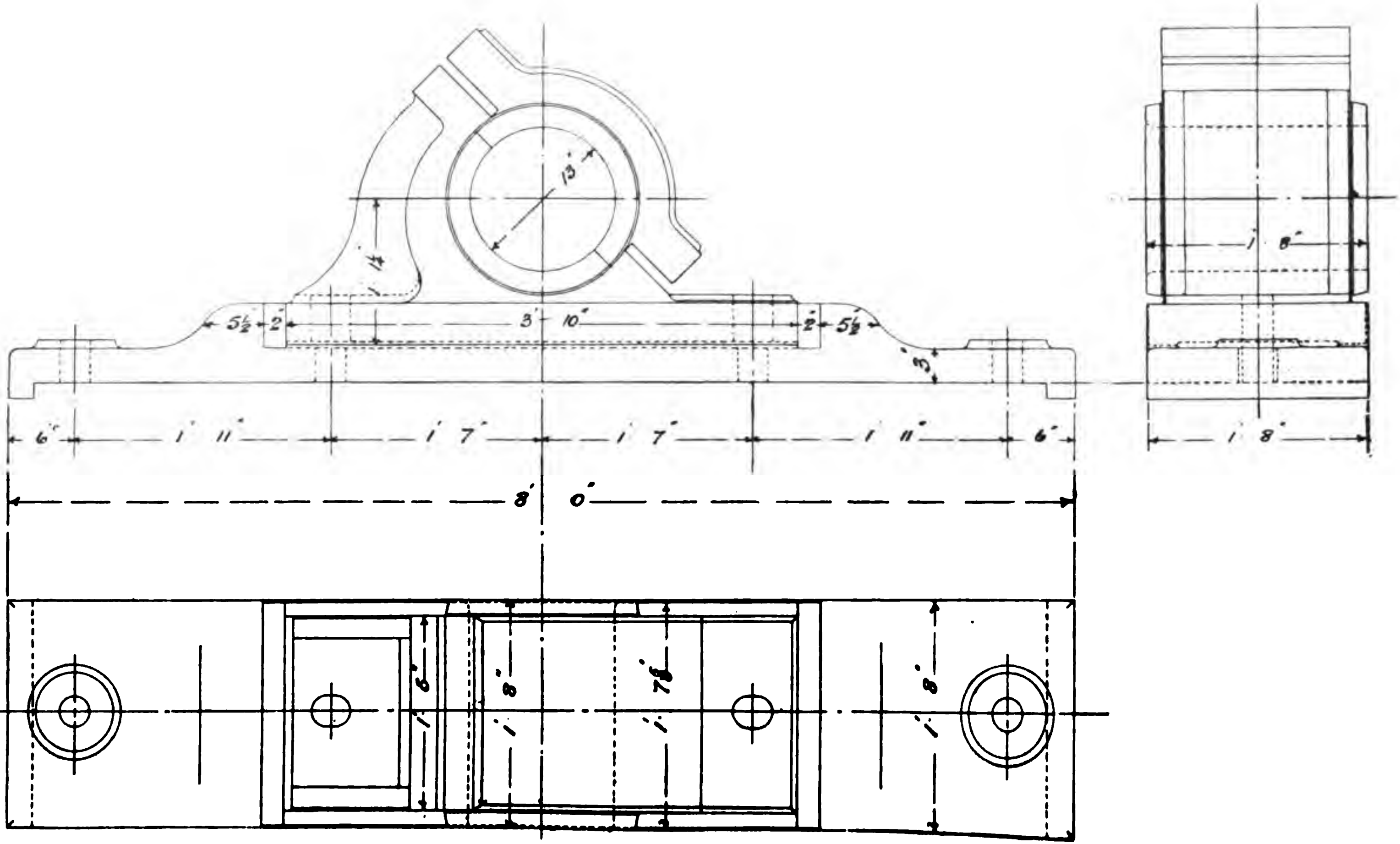


Fig. 358.—Plan and Elevation of an Angle Pedestal.

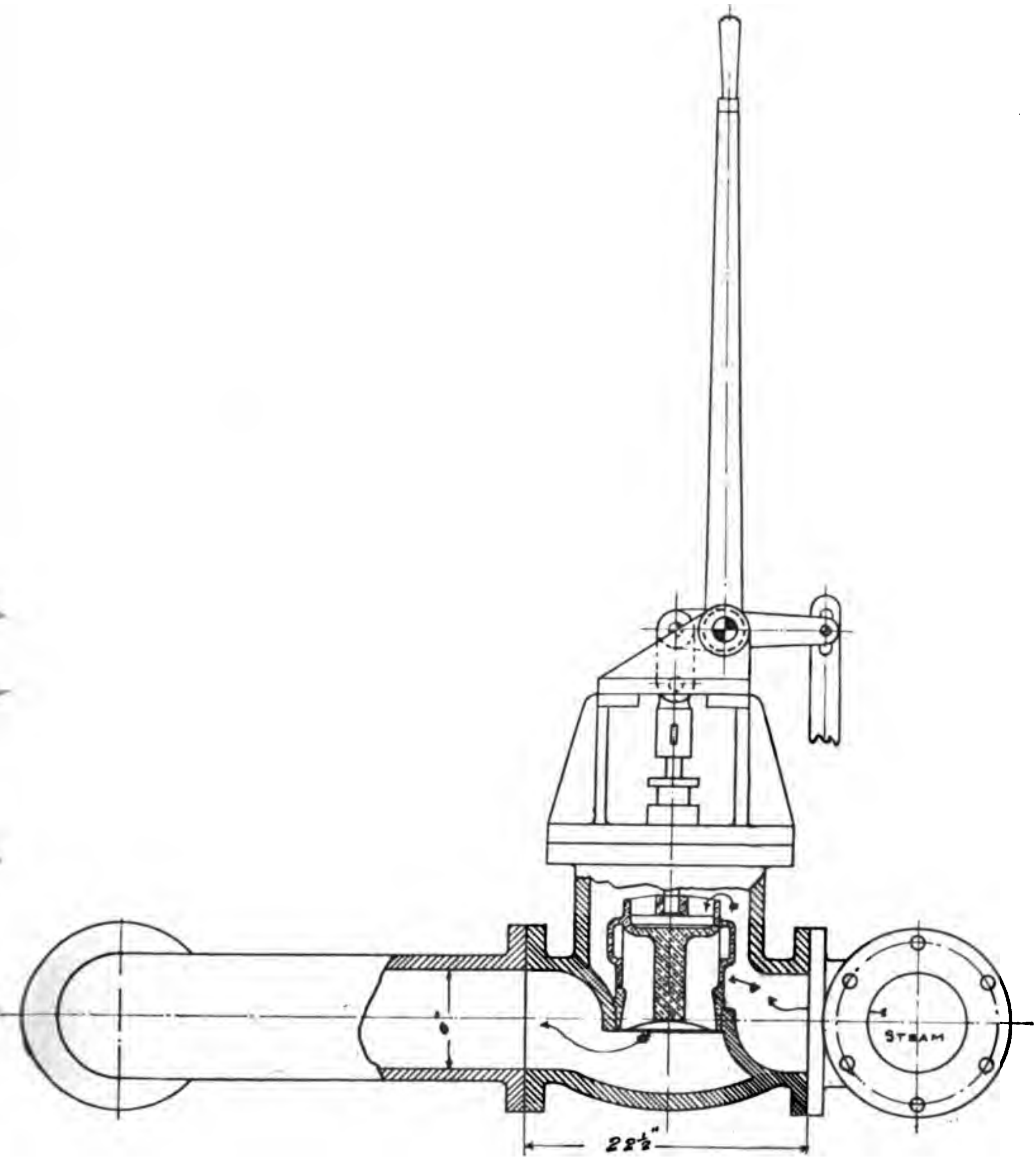


FIG. 352.—A CORNISH-TYPE STEAM THROTTLE VALVE FOR WINDING ENGINES.

The engine pillars for the usual type of horizontal winding engines afforded, and still afford, scope for simplicity, and at the same time excellence, in construction. They really have not a great deal to do except to provide a sufficiently substantial resting place for the engines; the height depends on the distance from the ground level to the level of the pit bank, because it is found convenient that there should be somewhat of a similarity between the floor of the engine house and the floor of the pit bank. The length and width of these pillars will depend on the length and width of each bedplate. The pillars of vertical engines are built of stone; this class of engine requires a pillar of firmness and substantiality, which can best be secured by solid ashlar stone. The pillar for the horizontal engine may be brickwork, with an ashlar top, or brickwork enclosing concrete, surmounted by an ashlar top, or concrete entirely. The engine beds should be well secured to their pillars, and the holes for the holding-down bolts should be well and truly brought up from the bottom to the top of the pillar. (*See fig.* 354.) The hand holes at the bottom, to enable the bottom fastening to be made, should be covered with cast-iron plates, and along these plates should be placed old railway metals, tieing the pillar together from end to end. In the Old Country, where we use a solid ashlar top, the whole of this top is dressed to fit the underside of the bedplates; in the United States of America this method is considered slow and needless, and the bedplate, standing a little above the top of the pillar, has the space filled in with cement, which is said to answer well enough.

Winding-engine houses should be arranged to give comfort to the engineman; this means ventilation, of which such buildings are woefully deficient. They should also provide means for effecting repairs. For very large engines a travelling crane used in erecting the engine is left as part of the permanent plant; where the engines are not of sufficient size to justify this, a good arrangement is shown on fig. 355. Figs. 356 and 357 represent a capstan engine. The space between the two pillars of the winding engine is often utilised for the accommodation of the capstan engine. The question has been raised as to whether it is good engineering policy to have two separate winding plants under

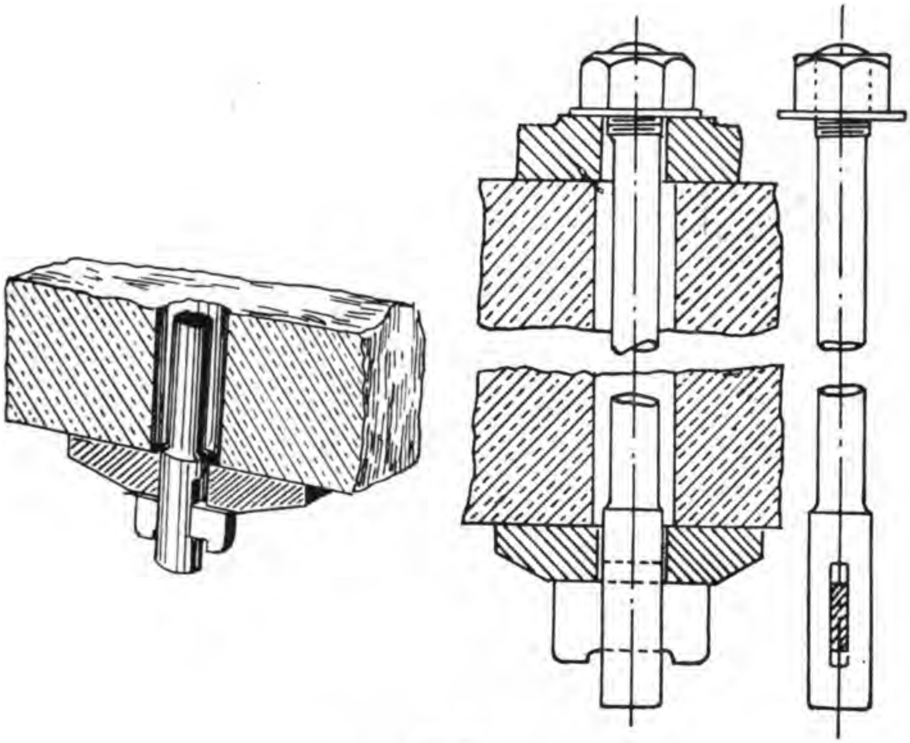


FIG. 354.
DETAILS OF HOLDING-DOWN BOLTS.

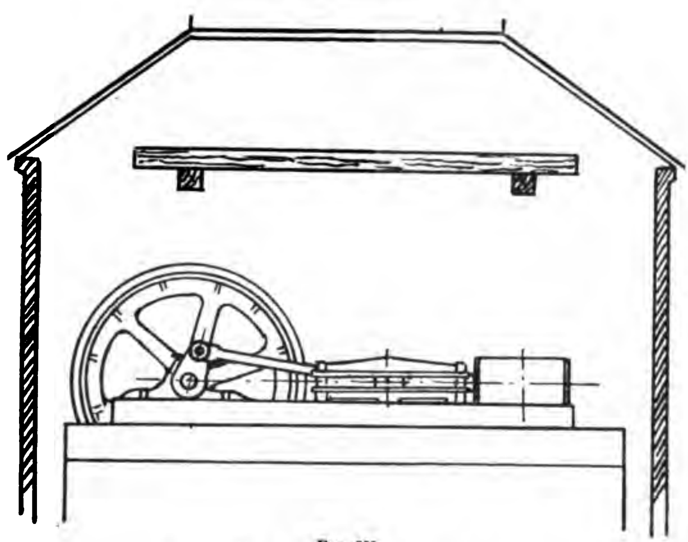


FIG. 355.
LIFTING BEAM FOR SMALL WINDING ENGINE.

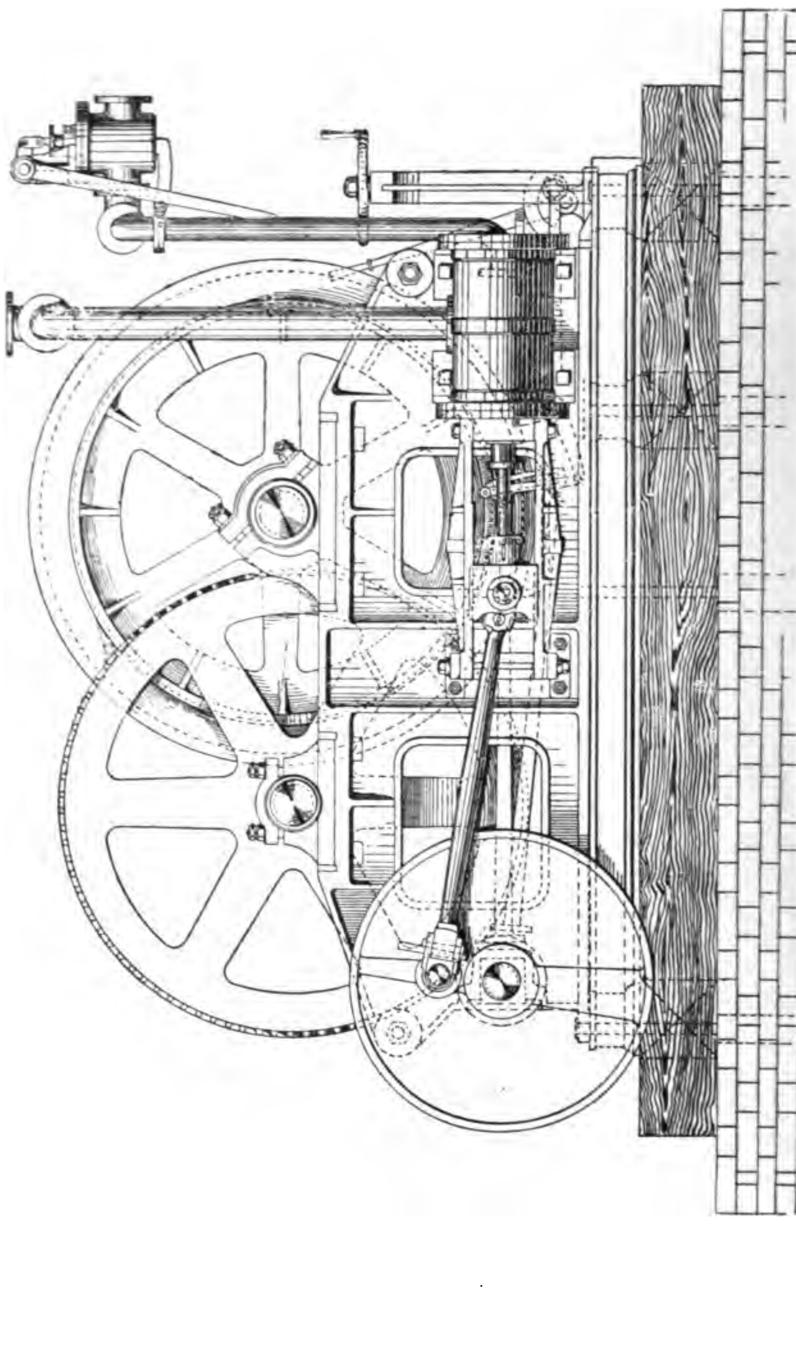


FIG. 856.—ELEVATION OF CAPSTAN ENGINE.

one roof, or whether each winding plant should have a domicile of its own. To have two separate plants in one engine house, open throughout, is wrong absolutely, for one

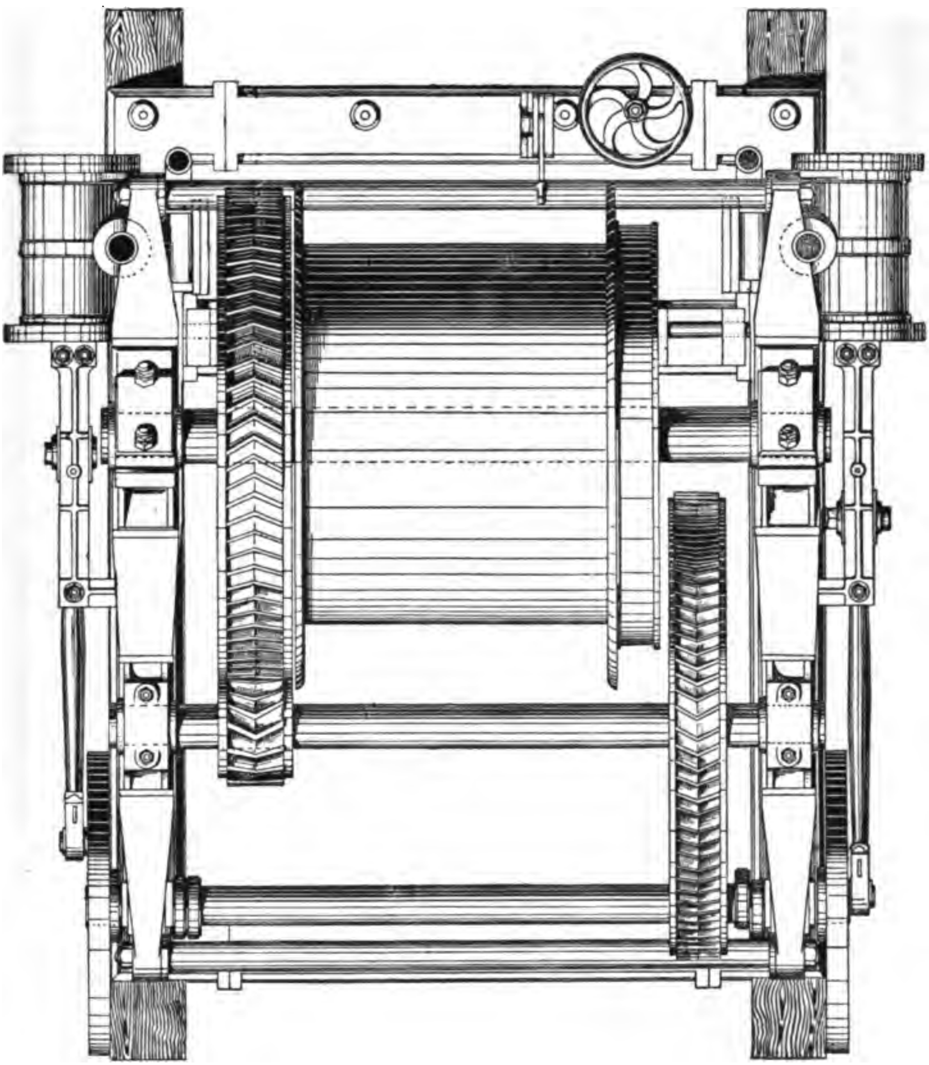


FIG. 857.—PLAN OF CAPSTAN ENGINE.

simple reason—there ought to be nothing in a winding-engine house which can distract the attention of a winding engineman. Not only is the working of one engine a distraction for the

other, but the presence of two winding enginemen in the same house affords a temptation to hold sweet intercourse together at the wrong time.

The brake of a winding engine is to answer the twofold purpose of helping to bring an engine to a stand and to hold it at rest when it has been brought to a stand. The Acts of Parliament mention an "adequate" brake. The meaning is a brake which, when the engine has been brought to a stand, will hold it at rest so long as no steam is applied. A good brake is an essential, and we want to be able to apply sufficient power and also be able to remove the brake and prevent it being a drag on the engine when supposed to be off. Figs. 358 and 359 show what we call an all-round brake, which probably never is free of its ring. A really good winding engine brake should be so designed that a very slight movement will put the brake either on or off, because it is on that very slight movement that we depend for the great leverage which gives us the power. To make this slight movement effective the all-round brakes are impossible. A good many later applications to winding engines have been what have come to be known as pillar brakes, the method of application being two vertical blocks, one at each extremity of a horizontal diameter and working together. Quite as good an arrangement is that in which the power is applied at the bottom of the drum. It is quite true that the utmost power that can be applied in such a case is the weight of the drum, etc., whereas in the pillar arrangement there is, theoretically, no limit, but in practice it will probably be found that all needful power can be applied under the drum. Of course we can have, and do have, steam brakes by means of which, if the brake cylinder is large enough, a very moderate leverage will provide enormous power. But all authorities are not agreed that steam brakes are best; they are very sudden and very severe in their action, and, whilst useful in an emergency, are not healthful to the machinery. When steam brakes are applied they should be such that steam will put them on. We mention this because a practice has prevailed that a deadweight should put the brake on and steam should take it off; if the steam pressure by any cause had fallen the brake could not come off.

For regular use a foot or hand brake may be accepted as the best; it may be so designed that only very slight effort is

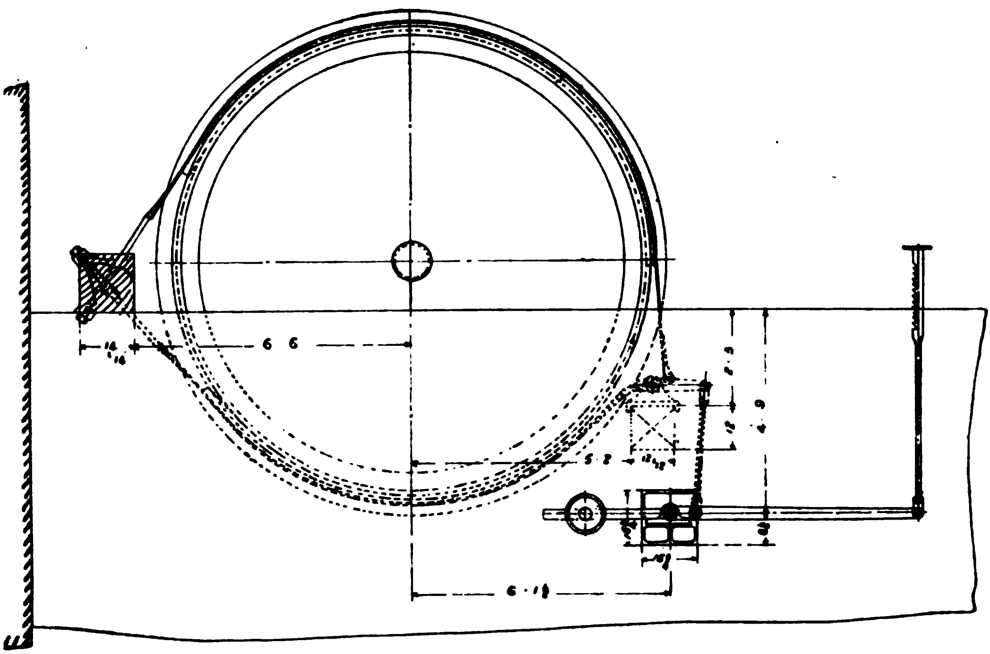


Fig. 858.—Elevation Showing Strap or All-Round Brake.

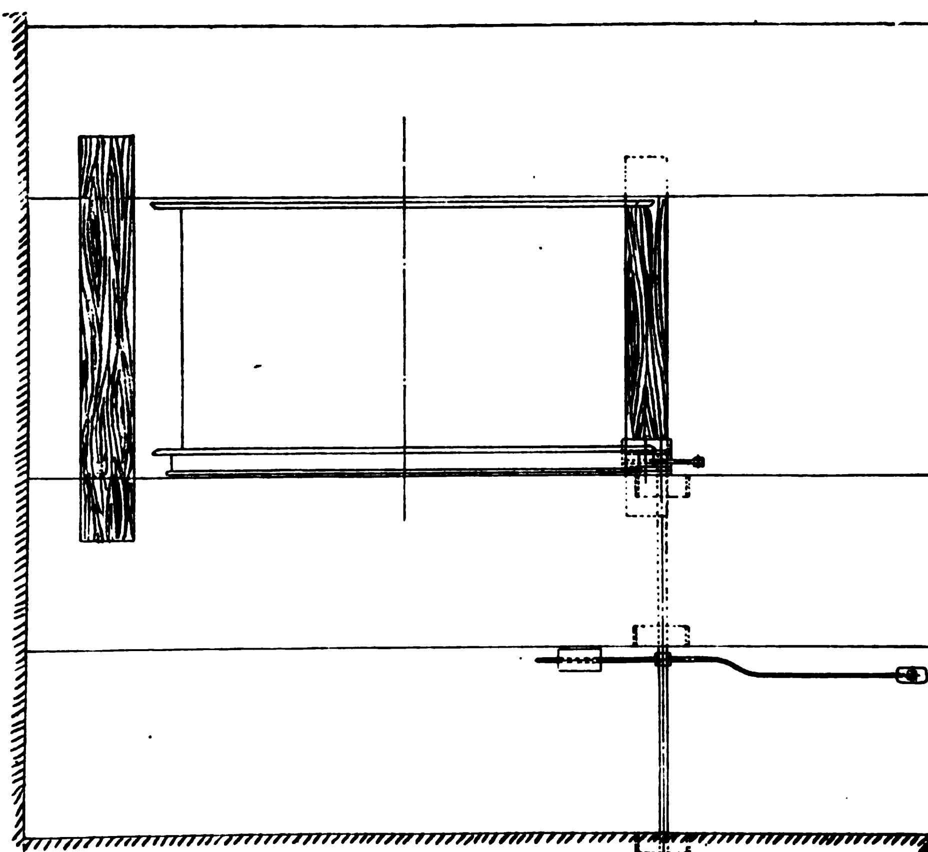


Fig. 859.—Plan Showing Drum Fitted with Strap or All-Round Brake.

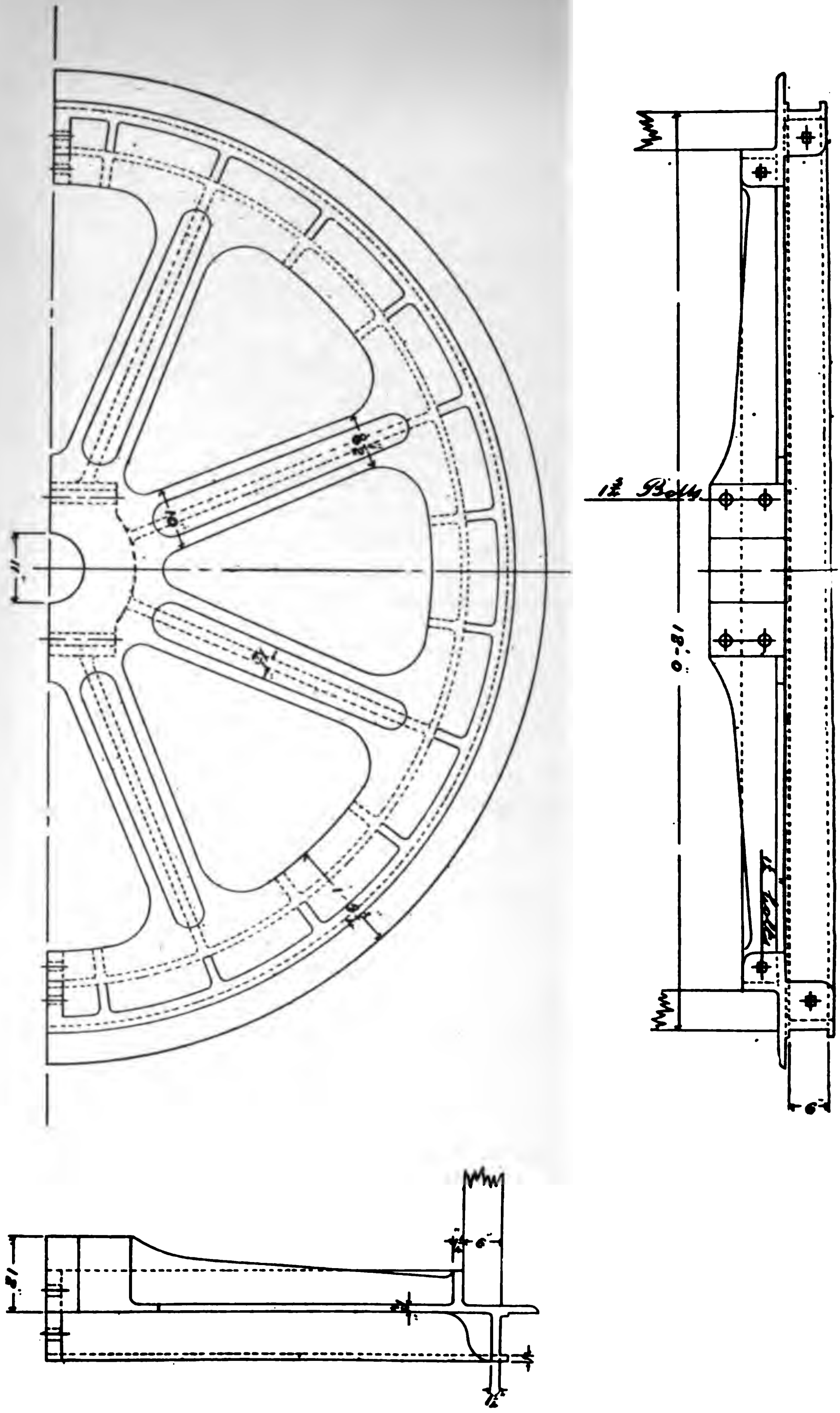


FIG. 859A.—DETAILS SHOWING THE BRAKE RING CAST ON THE DRUM, FIGS. 858 AND 859.

needed on the part of the engineman, and the action, whilst sufficiently effective, is more gentle. Figs. 360 and 361 (*see pages 574 and 575*) represent a good brake, easy of manipulation by the foot or hand. The power is applied to the lower part of the drum, and the medium of application is a block of wood, having perforations in the upper surface filled with sand, which keeps the brake surface clean and free from greasy matter. There is no difficulty in obtaining a leverage of two hundred, so that each ten pounds applied by the hand or foot transmits one ton to the brake block. An adjusting screw is provided to enable the appliance to be set to a nicety.

As we have remarked elsewhere, the winding engine should be so equipped that its manipulation and control does not involve a considerable amount of physical exertion tending to fatigue.

The engineman must ever be on the alert, his attention concentrated upon the operations of the machinery, which should respond to every movement of the controlling appliances with mathematical precision, and it is unfair to the engineman, and to those whose safety depends upon his care and skill, if the controlling appliances require considerable physical effort for their operation.

A modern winding engine is made easy in manipulation with the provision of well-balanced, quick-acting throttle valves, powerful foot brakes supplemented with an auxiliary steam brake, and in the case of large engines, or engines with heavy valve gear, a steam reverser is applied.

The steam reverser illustrated in fig. 362 (*see page 576*) is typical of these appliances; it represents Melling's steam reverser, made by the Worsley Mesnes Ironworks Company.

The Melling steam reverser consists of a steam cylinder, **AA** in the illustration, and a water cylinder **BB** immersed in a water tank. The function of this water cylinder is not only to steady the action of the reverser and prevent jerkiness, but also to automatically secure the appliance in any desired position, according to the position of the reversing handle.

The steam supply to the steam cylinder, and the water supply to the water cylinder, is controlled by a series of small piston valves on the rod **H**, which is operated by the connecting link **G**, worked from the reversing handle through the lever **E**.

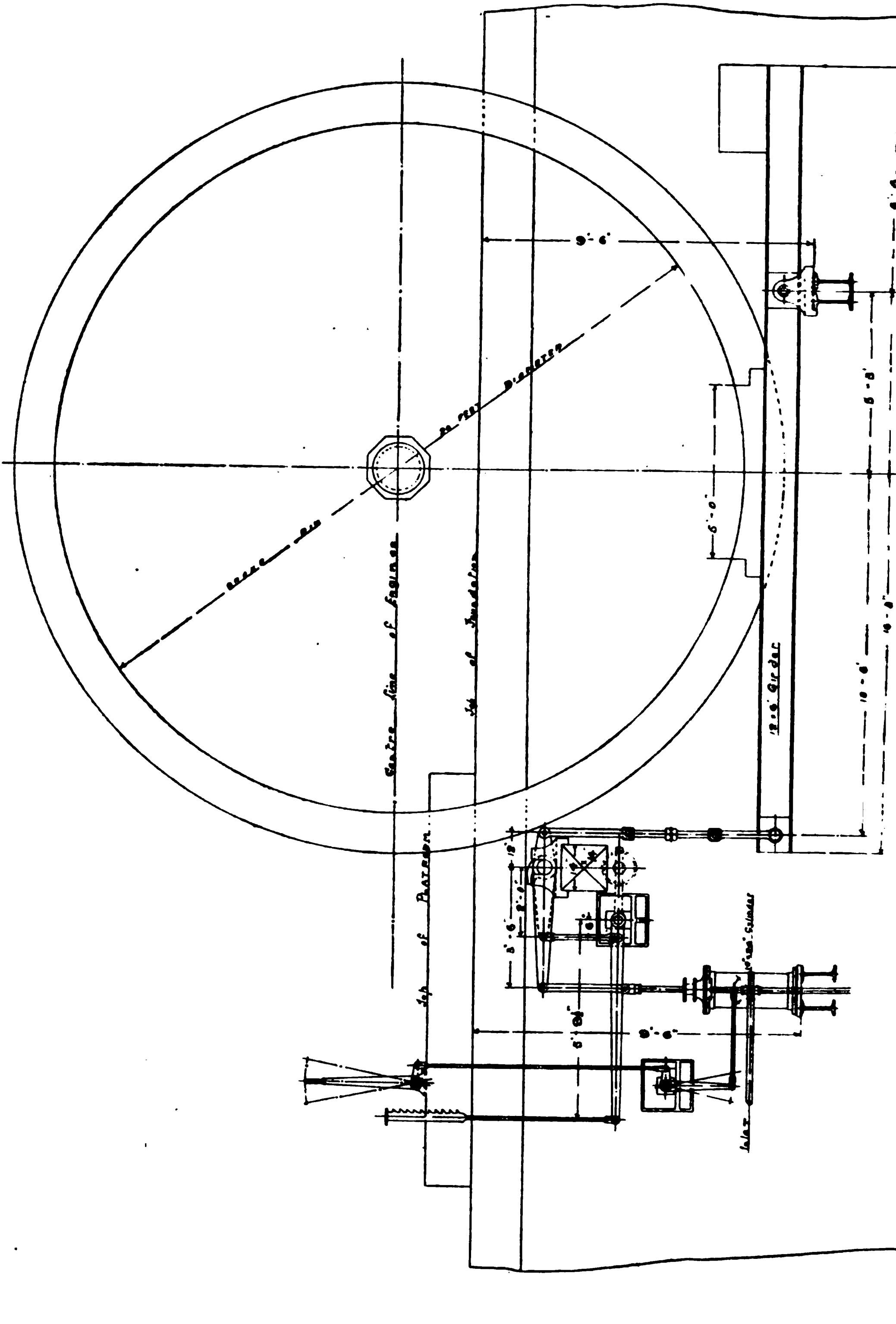


FIG. 360.—ELEVATION SHOWING BURR'S BRAKE WITH FOOT AND STEAM GEAR.

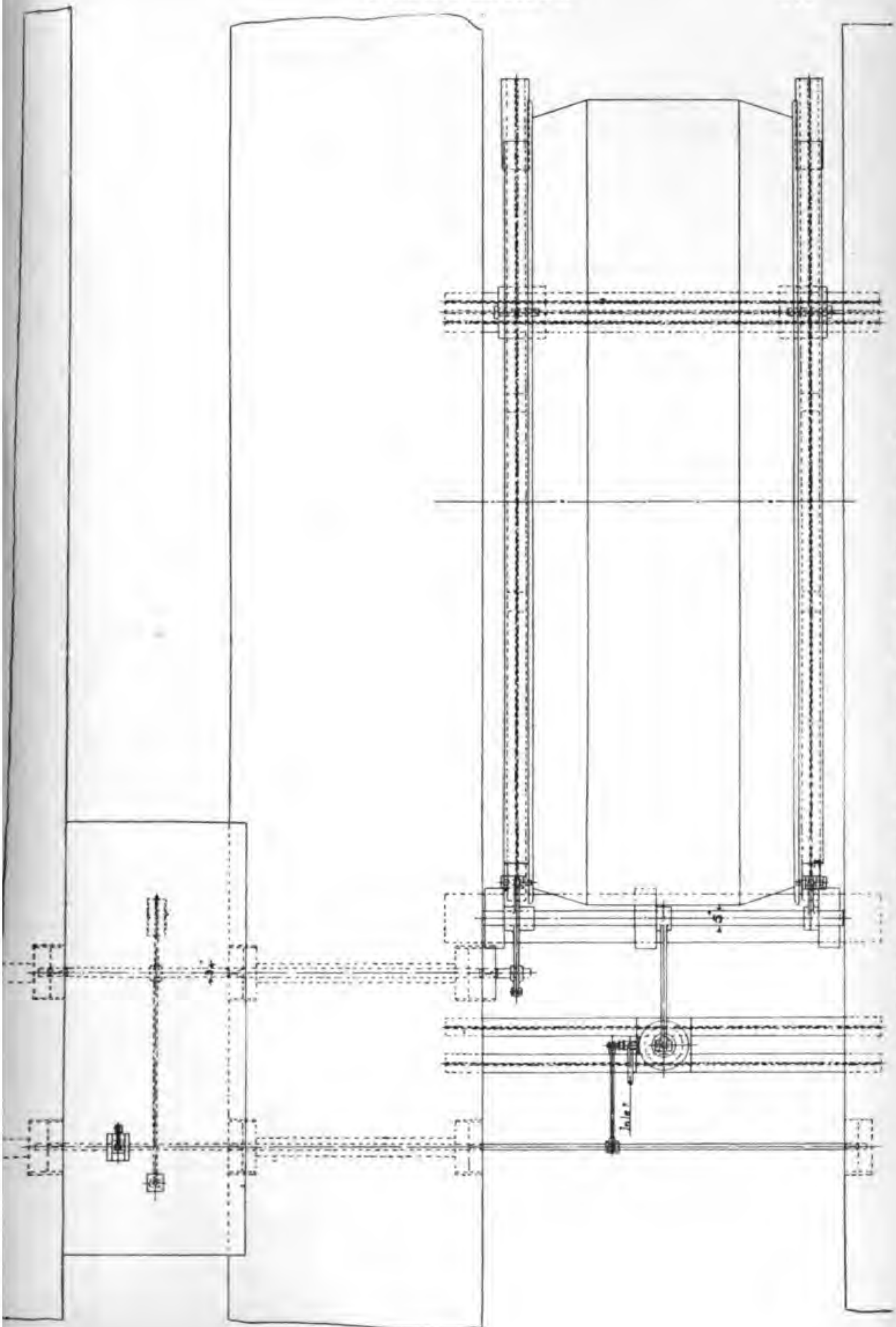


FIG. 301.—PLAN OF 20-FOOT DRUM FITTED WITH BURN'S BRAKE OPERATED BY FOOT OR STEAM.

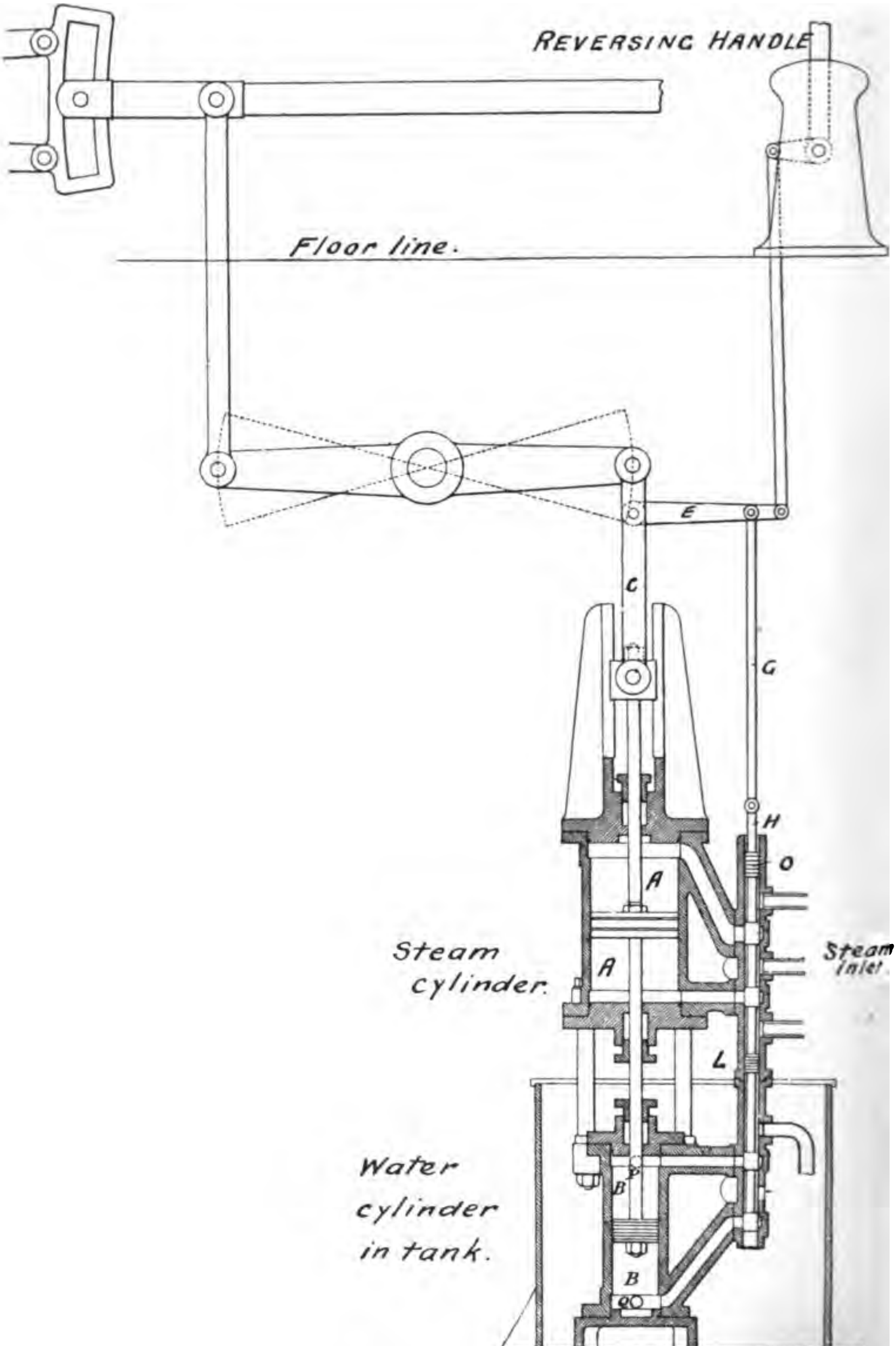


FIG. 362.—MELLING'S STEAM REVERSER.

The three pipes on the right are the steam inlet and exhaust, the middle one the inlet, and the upper and lower ones the exhaust pipes. As shown in the illustration (*see fig.* 362) the reverser is in the middle position. Now, suppose the reversing handle is moved forward, thus lowering the connecting link **G**, and opening the steam admission for the lower side of the cylinder, and similarly opening the water inlet and outlet for the water cylinder, which draws from and discharges into the tank.

Steam being admitted to the underside of the cylinder, the piston is forced upwards, and operating through **C** and the reversing mechanism, pulls down the rod connecting the engine slide valve with the eccentric link. In the meantime, the ascent of the piston, operating through the lever **E**, has raised the piston valves into the original position, closing all the passages, both water and steam, thus holding the reversing gear securely in position.

In like manner, if the reversing handle is pulled back, the piston valves are raised, opening steam and water admission to the upper sides of the pistons, the result being a downward movement and the reversal of the engine. Again, the lever **E** brings the piston valves back into the original position, and securely holds the reversing gear in the desired position; indeed, it may be said that the position of the piston valves, as shown in the illustration, is the normal position, and however the reversing handle is moved, backward or forward, much or little, the valves are always brought back into this position. The engineman therefore moves his handle into any desired position, with the certain knowledge that the reversing gear will assume a corresponding position, and so remain until the handle is again moved.

EXAMPLES AND CALCULATIONS.

At this stage it will be useful to introduce one or two simple examples showing how to calculate the size of winding engines for given conditions, and although the examples we shall give may not be quite suited to the taste of the fastidious mathematician, they have at least the merit of being practical, and enabling us to obtain correct results, whilst being intelligible to those of our readers who find some difficulty in following out

the involved and complicated formulæ, which may be more exact mathematically, but which lead to the same result practically.

The winding engine must be so proportioned that it can deal with the maximum load in the most unfavourable position, and be able to develop at starting that excess of power necessary to get up speed in a reasonable period of time.

We are acquainted with many colliery winding engines, excellent as examples of good machinery, but disappointing as examples of good colliery engineering. Either they start with difficulty when one engine is on dead centre, or they take so long to get up speed that a high speed is never really attained, and the period of winding consequently longer than need be, which means limiting the output of the mine.

If a colliery is to have a large and steady output, its winding engines must be capable of starting easily and attaining a reasonably high speed in a reasonable space of time.

The proportion of the winding engine is largely a question of the relative speed of the pistons and the cage.

There has been a tendency of late years in the direction of very large drums, 25 and 35 feet in diameter, and whilst these large drums can well enough be constructed of steel, much lighter in proportion than the older cast-iron drum, we are inclined to advocate the adoption of light built-up steel drums of moderate size, and a higher piston speed.

The winding drum must be strong, and at the same time, to reduce the load due to inertia, must be as light as is consistent with strength.

Example: As a first example we will calculate the size of a pair of simple horizontal winding engines, with plain parallel drum and no balancing of the rope, for an output of about 1400 tons per day of 8 hours, from a depth of 500 yards.

The rule we shall adopt is the following: Having decided upon the ratio of the speed of the cage and the speed of the piston, from 4 to 1 to 6 to 1, according to circumstances, multiply the total load against the engine in pounds by this ratio, and divide by the average effective steam pressure in pounds per square inch, which gives the area of *each* cylinder in square inches.

The stroke is about twice the diameter, and the circumference of the drum is twice the stroke in feet multiplied by the speed ratio decided upon.

From a depth of 500 yards, with good appliances, it should be an easy enough matter to wind sixty times per hour, and with cages holding six wagons of 10 hundredweights' capacity each, this amounts, in the eight hours, to well over 1400 tons.

As the rope is unbalanced it becomes necessary in the first instance to arrive at the weight of the rope:—

	Pounds.
Coal, 1120 × 6	6,720
Wagons, 5 hundredweights each × 6 ...	3,360
Cage, etc., say	6,000
	16,080

applying the rule given on page 497: $\frac{16,080}{2000-500} = \frac{16,080}{1500} = 10{\cdot}72$ pounds per yard, say $10\frac{3}{4}$ pounds per yard, equal to a rope $4\frac{5}{8}$ inches circumference: $10{\cdot}75 \times 500 = 5375$ pounds of rope.

The load against the engine is made up of the coal and the rope:—

	Pounds.
Coal	6,720
Rope	5,375
	12,095

to which we must add something to represent the friction of the engine, pulleys, etc. It will not be unreasonable to add 50 per cent, which is equal to an overall efficiency of 66·6 per cent.

	Pounds.
This brings the load against the engine to ...	12,095
Add 50 per cent	6,047
	18,142

We shall assume a speed for the cage at four and a half times the speed of the piston, and seventy pounds per square inch average effective pressure of the steam (about two-thirds of the boiler pressure): $\frac{18,142 \times 4{\cdot}5}{70} = 1166{\cdot}27$ square inches area of *each* cylinder, say 39 inches diameter by 6 feet 6 inches stroke. The drum will be 6 feet 6 inches × 2 × $4\frac{1}{2}$ = 58·5 feet circumference, or 18 feet 6 inches diameter.

It will be observed that we have taken the calculated area as being the size of *each* cylinder, so that in providing *two*

cylinders, each equal to the load, we are, at first sight, making our engine twice as large as need be. We have to remember two things, however: first, that it is possible the engines may have to start in such a position that only one engine is capable of exerting any power, the other being on dead centre, and therefore powerless; and secondly, we have to provide an excess of power over and above that represented by the load to be raised, in order to get up speed; indeed, as we have already explained by means of the diagram (*see fig*. 330, *page* 542), the engines may be called upon at the commencement of the wind to exert an effort more than twice as great as the force necessary to raise the coal and the rope. There is therefore nothing inconsistent in making the calculation as if for an engine with one cylinder, and adding a second of similar dimensions.

As a further example we may take the following—namely, a pair of winding engines for a shaft 900 yards deep, from which it is intended to raise about 1100 tons per day of eight hours; steam pressure at the boilers, 120 pounds.

We propose to work out this example, first, with a balanced rope—that is, a tail rope under the cages—and secondly, without a balance rope.

From this depth, 900 yards, with good appliances we shall be able to wind 320 times per day of eight hours (forty runs per hour.)

Double-decked cages, three tubs per deck, of twelve hundredweights' capacity each, will therefore enable us to raise more than 1100 tons per day.

As the rope is balanced we have to consider the coal and frictional resistances only:—

	Pounds.
Coal, 3 tons 12 hundredweights ...	8,064
Add 50 per cent...	4,032
	12,096

Say 12,100 pounds.

As the load is comparatively light and the depth considerable, we shall take 6 to 1 as the ratio of cage and piston speed: $12{,}100 \times 6 = 72{,}600$, and 72,600 divided by 80 (two-thirds of the boiler pressure) $= 907{\cdot}5$ square inches area of each cylinder, in round numbers say 36 inches diameter by 6 feet stroke.

The drum will be $6 \times 2 \times 6 = 72$ feet circumference, say 23 feet diameter.

The cost of such a winding engine, fitted with automatic trip expansion valve gears, would be about £4000.

Taking the same conditions, but without a balance rope, we have :—

	Pounds.
Coal	8,064
Cage, say	6,000
Tubs	4,032
	18,096

and $\frac{18{,}096}{2000 - 900} = \frac{18{,}096}{1100}$ equal, say, 16 pounds per yard, or about $5\frac{3}{4}$ inches circumference.

Load against the engine :—

	Pounds.
Coal	8,064
Rope, 900×16	14,400
	22,464
Add 50 per cent.	11,232
	33,696

Take 4 to 1 as the ratio of speed: $\frac{33{,}696 \times 4}{80} = 1{,}684{\cdot}8$ square inches area of each cylinder, or, say, 46 inches diameter by 7 feet 6 inches stroke.

Drum, 7 feet 6 inches $\times 2 \times 4 = 60$ feet circumference, say 19 feet diameter.

COMPOUNDING AND CONDENSING APPLIED TO COLLIERY WINDING ENGINES.

It may have been noted by some of our readers that we assumed a rather high average effective steam pressure. As a matter of fact, in a modern winding engine, although during the first two or three revolutions of the drum the average steam pressure will be high, expansive working is automatically introduced as the engine gains in speed, and the steam is cut off earlier in each succeeding stroke until quite possibly in some cases the steam is cut off entirely for a considerable portion of the winding.

This expansive working tends in the direction of economy in steam consumption, for which, as we have already indicated, there is ample scope.

It will be understood that a definitely fixed point of cut-off, such as may well be provided, say, in a fan engine, will not do in the case of a winding engine. Suppose we made the attempt, and set the valves to cut-off at half stroke. It will be evident that if the engines had to be started under the conditions previously referred to, one engine on dead centre, a serious difficulty would arise; indeed, the engines could not be started from that position, because whilst one engine is powerless the other engine can receive no steam.

A fixed point of cut-off, too, interferes with the control of the engine, and for these reasons a winding engine is rarely arranged to work expansively in the ordinary way.

A winding engine must be under the full control of its attendant at every point, and the expansion mechanism, whilst providing a means of cut-off when the engine has got up speed, should not interfere with the engineman's control.

Quite a number of arrangements of automatic expansion gears are available. The first with which the writer became acquainted was brought under his notice by Mr. Arthur J. Stevens, of the Usk Side Ironworks, Monmouthshire; and although it turned out that this very gear had been anticipated by Messrs. Musgrave & Sons, of Bolton, Lancashire, a friendly arrangement was arrived at, and the writer certainly feels himself none the less indebted to Mr. Stevens, who, unknowingly, followed in the groove of a previous inventor. The arrangement is illustrated in fig. 363. **A** is the valve spindle of one of the steam Cornish valves, and **B** is an ordinary form of lifter. In non-expansion engines the lifter **B F** communicates its motion to the bridle **C**, or to the valve spindle **A**, and the valve spindle follows the motion of the lifter both up and down. In this arrangement the lifter **B F** communicates motion to the bridle **C** through the intervention of the bell-crank lever **H G**, which is attached to the bridle by means of a pin at **D**. **M** is an air dashpot of any convenient form, with an inlet valve **N** and a regulating cock **O**. Upon the frame **L**, which carries the dashpot, are fixed two bearings **P**, which carry a small spindle **S**, having an eccentric **J** fixed or fitted thereon. The rod **R** is

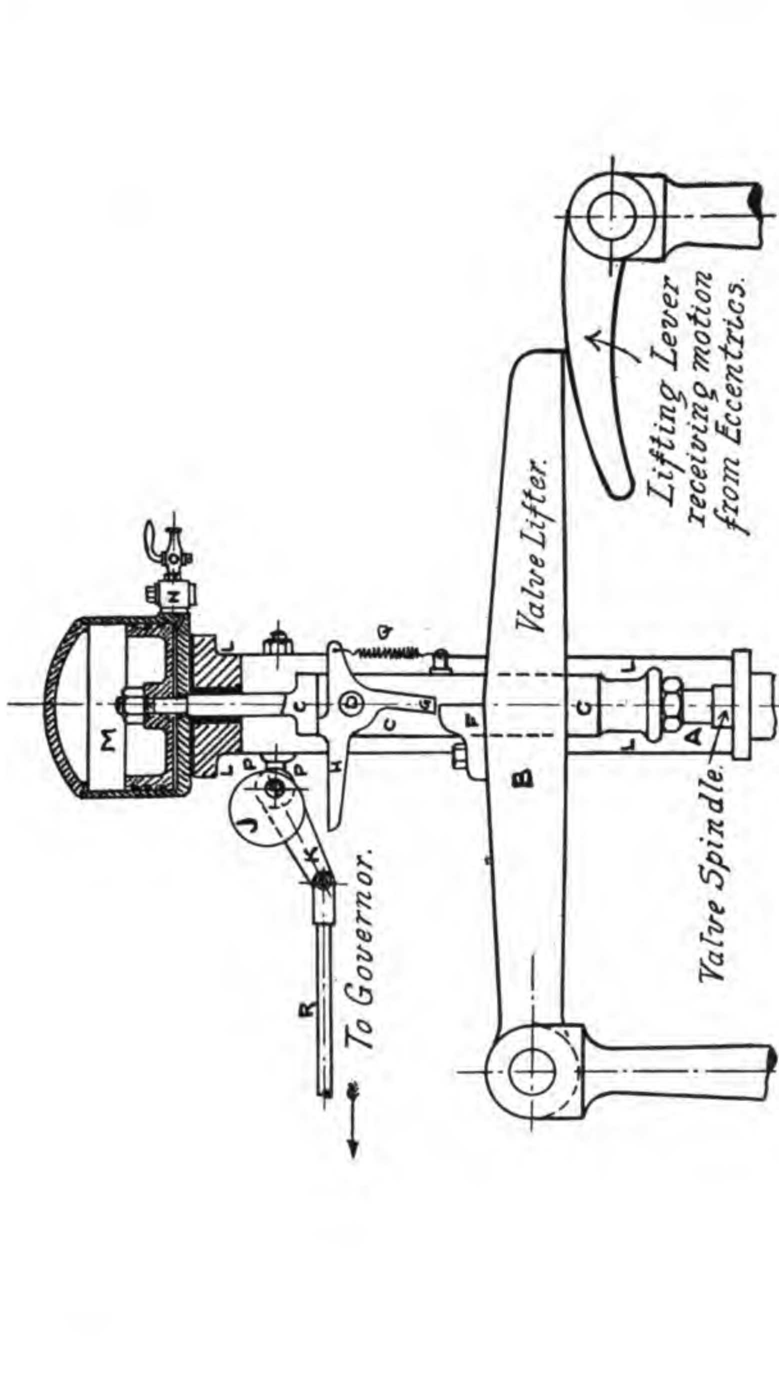


Fig. 303.—Illustrating the Mechanism of Automatic Expansion Gear for Winding Engines.

moved backwards by the governor, and by means of the lever K causes the eccentric J to make a partial revolution, so that when the governor is full up the throw of the eccentric J is in a downward direction. The action is as follows: When the engine is standing or running very slowly all the parts will be as shown in fig. 363 (*see page* 583), and the lifter BF will, during the whole time, be in contact with the bell crank HG, and the valve will act as though no expansion gear were present. But when the engine is running fast, and the governor more or less near its highest position, the eccentric J is turned downwards, and as the valve spindle rises the eccentric will come in contact with the bell crank at H, and cause the other end G to trip off F, and allow the steam valve to drop, thus shutting off the steam from entering the cylinder; the lifter will continue its upward motion unaccompanied by the bridle, and on its descent the spring Q will bring the bell-crank lever into gear again. The grade of expansion will thus vary with the position of the governor, and consequently with the speed of the engine.

Sometimes, as in the raising and lowering of workers, it is thought desirable to be free of automatic expansion gear; the disconnection, if desired, is a simple matter. Fig. 364 gives a diagram from a winding engine to which the gear was applied, showing the action in the cylinder just before the expansion gear came into play; and also one taken whilst the expansion gear was in action; the two diagrams speak for themselves. In the one case we have steam at full pressure all through the forward stroke, and very great back pressure in the return stroke; in the other case we seem to cut off at one-fourth, an excellent expansion curve is produced, and the back pressure of the return stroke is almost non-existent. Experiments which have been made as to the consumption of steam with and without expansion gear amply demonstrate the economy effected by their application.

It will be accepted without further elaboration that both condensing appliances and expansion arrangements are necessary for economy, and that they not only can be applied to winding engines, but have been successfully applied for a considerable period. The expansion mechanism, which we have described and illustrated, is a fairly good type even yet of that class of winding-engine improvements. Condensing arrangements have

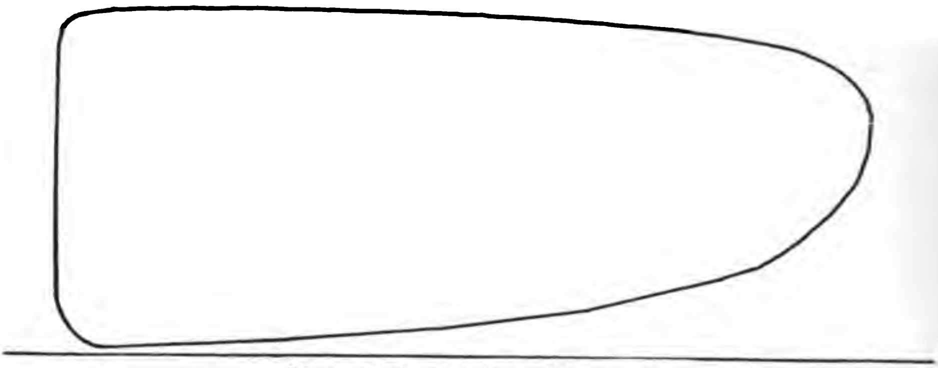
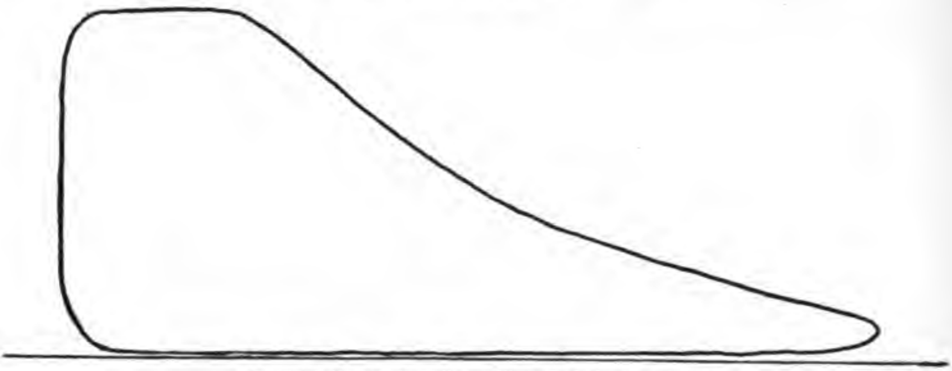


Diagram with Expansion Gear not in Operation.



Expansion Gear in Operation, cutting off at about one-fourth.

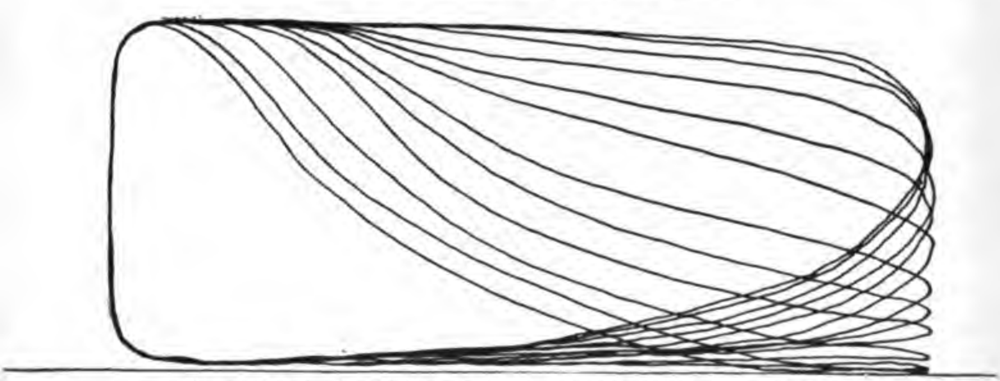


Diagram of a Complete Winding with the Expansion Gear in Action, and cutting off earlier in each succeeding stroke.

Fig. 364.

Diagrams from Winding Engine fitted with Automatic Expansion Gear.

been substantially improved upon, and a favourite method is to have the condensing part of the machinery self-contained—that is to say, that without interfering with the intermittent operation of the winding engine proper, the condensing machinery can go on continuously.

We have illustrated and described (*see pages* 87 *to* 98) several types of central or independent condensing arrangements, such as have been successfully applied at modern collieries to deal both with the exhaust steam from the winding engines and other steam engines at work upon the surface.

It is possible, of course, to carry out a system of expansion in one cylinder, but there are advantages in the adoption of two cylinders, because the extent to which we can expand in practice effectively is somewhat limited; high rates of expansion in one cylinder are not always desirable. The compound arrangement of having two cylinders or more—but two may be taken as a maximum for our present purpose—gives us scope for a considerable range without the disturbing influences of inequality of temperature and inequality of strain upon the engine. Suppose we wanted to expand nine times; to do so in one cylinder would give us much variation of temperature, and would also throw a variation of strain upon the engine of 1 to 9. But suppose we arrange to expand the nine times in two cylinders, the arrangement would be three expansions in the first or high-pressure cylinder, and three expansions in the second or low-pressure cylinder. Suppose we commenced in the first cylinder with a pressure of 72 pounds per square inch, three expansions would bring this pressure down to 24 pounds; this would be passed on to the second cylinder, and three expansions would bring the pressure down still further to 8 pounds, being a total fall from 72 to 8, or nine expansions in all; and yet we should only have a variation of 1 to 3 in each cylinder. In such an arrangement the two cylinders should be so proportioned that the area of each multiplied by the average effective pressure in each would give a similar result. In our particular example this would be accomplished by making the second cylinder three times the area of the first cylinder. It will occur to our readers that the problems concerning deep mining will force the consideration of effective winding machinery, so that the

greatly-increased depths from which coal will have to be raised as the twentieth century progresses will not throw anything like a proportionate increase in the consumption of coal for steam generation.

THE WHITING SYSTEM.

The enterprising firm of Fraser & Chalmers Limited, whose works are established in the county of Kent, have done much to make possible winding engines of greatly increased power and greatly increased economy, both of which are essential, and the writer is indebted to that firm—of whose productions he has the highest possible opinion—for valuable information. Amongst other useful particulars are some relating to what is called the Whiting system, illustrated upon figs. 365 and 366. (*See pages* 588 *and* 589.) It would appear to be intended to avoid massive winding drums, and also to avoid the rope coiling upon itself, and to arrange for the use of small drums and round ropes, passing the rope round one or two grooved drums, and balancing the cages, so that the rope simply passes a few times round the drum and off again. First applied in America, it has been adopted in the Rand mining district of our South African dominions. The rope passes several times round two drums, which, as a rule, are both driving drums. One end of the rope is made fast directly to one cage, from which it passes over the headgear pulley to the driving drums on the engine, thence it passes away from the engine to a pulley mounted on a carriage running on rails in a long extension or annexe of the engine house; the rope takes a half turn round this pulley and passes back towards the shaft, under a deflecting pulley, and over the second headgear pulley to the other cage. The carriage affords a means of adjusting the position of the cages for winding from different levels in the shaft. In the Whiting system the exact depth of the mine need not be determined at the commencement, as the rope can be adjusted to suit requirements. To preserve the uniformity of the load the tail rope, which is in no sense peculiar to the system, is adopted. Both drums are positively driven by the engine; the first drum is driven directly by the main connecting rods, whilst the second drum is driven by means of a pair of parallel

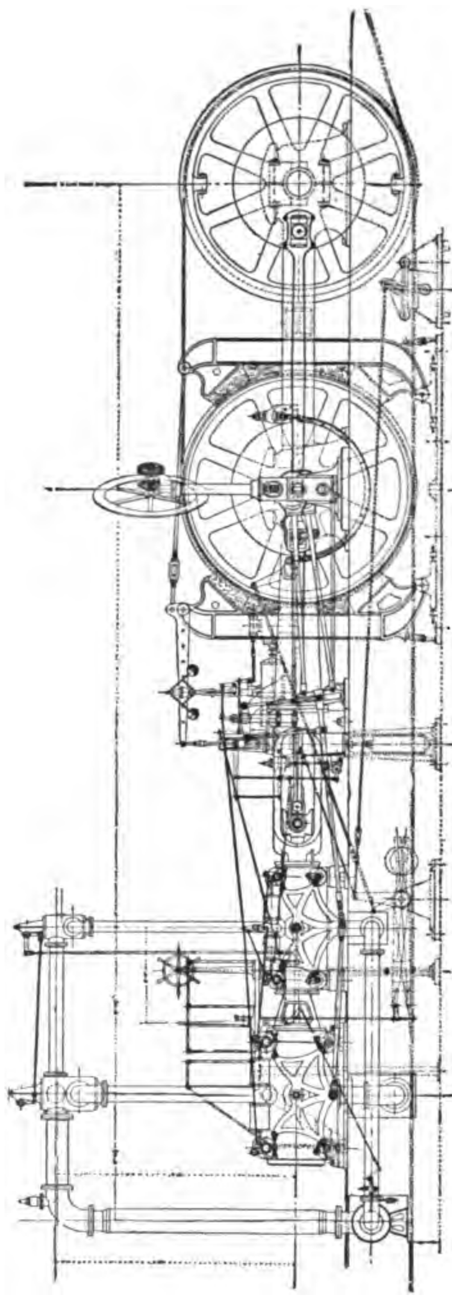


Fig. 365.

Elevation of a Double-Tandem Compound Winding Engine arranged for the Whiting System of Winding.

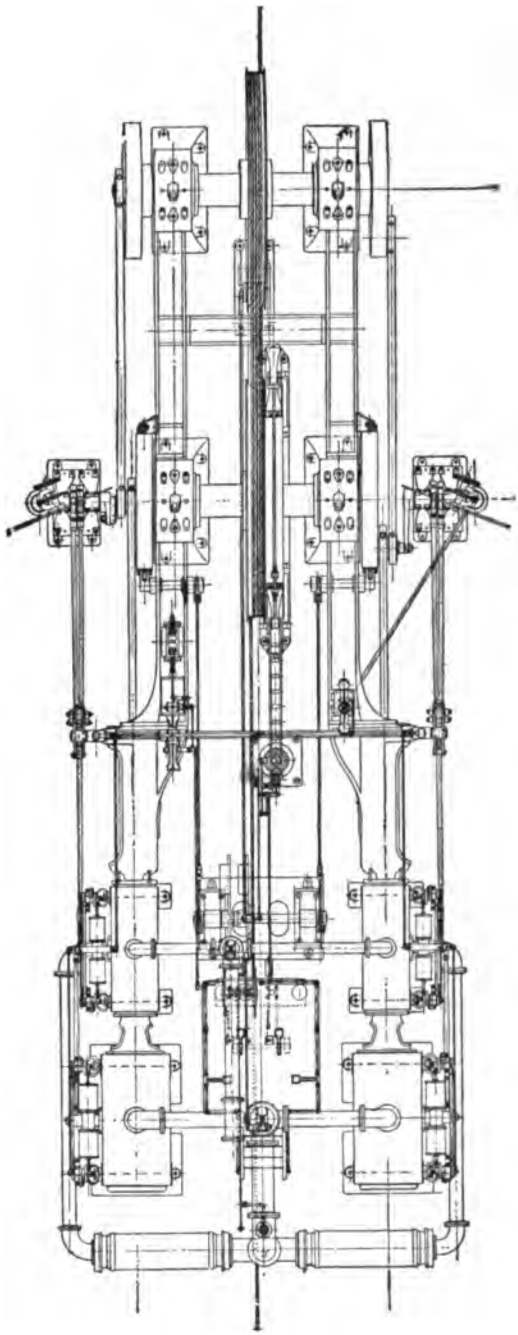
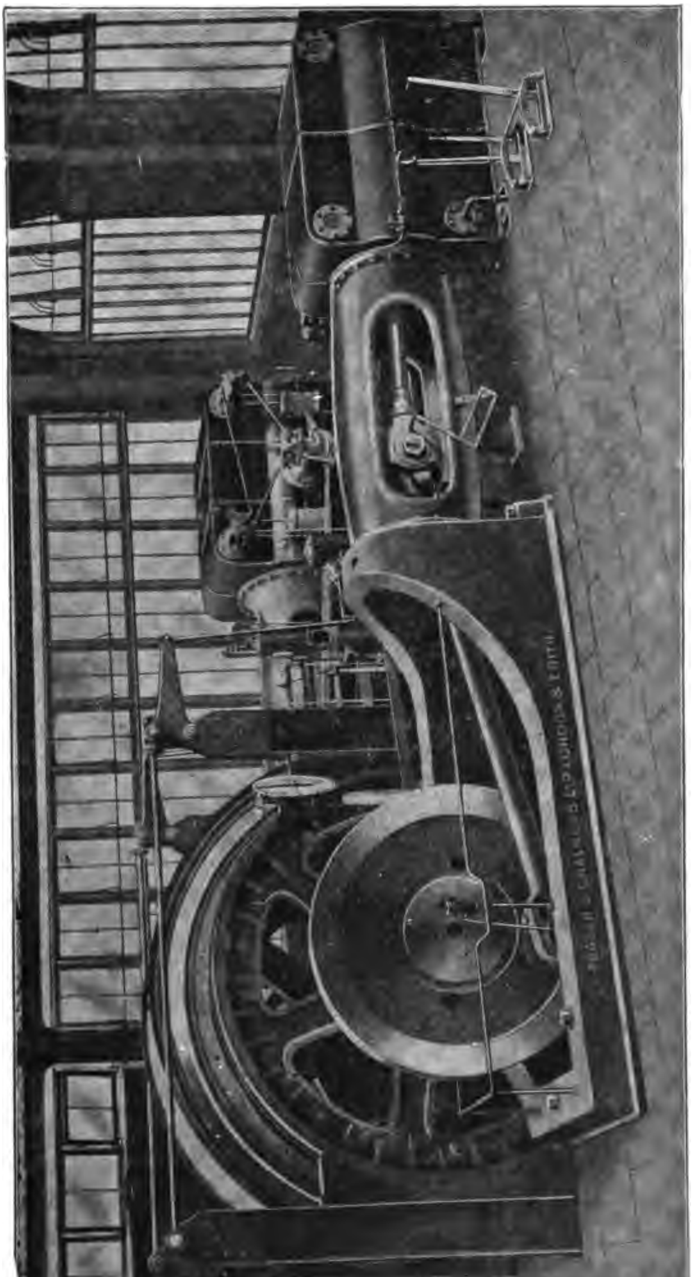


Fig. 366.
Plan of Double Compound Winding Engine arranged for the Whiting System of Winding.

rods similar to those used on locomotives. Only one of these drums needs to be provided with a brake wheel.

The usual type of winding engine applied to the system is what is called a cross compound Corliss, with one high-pressure and one low-pressure. The term "cross compound" arises from the fact that it is really a pair of engines, with one cylinder to each crank. There are applications, however, of what we call double-tandem Corliss engines which have a high-pressure cylinder and a low-pressure cylinder attached to each crank. The engine may, if desired, be simple high-pressure. And there is still another arrangement of four-cylinder triple-expansion engine, with a high-pressure cylinder and an intermediate cylinder attached to one crank, and a high-pressure cylinder and a low-pressure cylinder attached to the other crank. The cross compound type is said to be the best. An automatic governor forms part of the mechanism which controls the cut-off, and is so arranged that it will automatically throw the cut-off gear out of action while the winding engine is being slowed down. The particular arrangement which attracted our attention is not very great in the matter of dimensions, having a high-pressure cylinder 17 inches diameter, and a low-pressure cylinder 28 inches diameter, the stroke being five feet, but they are said to be capable of raising a load of 8000 pounds from a depth of 5000 feet. If our winding engines are such that the load is properly balanced, the question of size is really not affected by the depth, except in so far as we usually increase the load, if possible, for greater depths, so as to give us a profitable output. The cages, etc., should balance each other, and the only load during the winding upon the engines should be the weight of coals.

The following particulars, relating to the application of the arrangement at the Red Jacket shaft of the Calumet and Hecla Copper Mines on Lake Superior, may be of interest. The pit shaft is about 5000 feet in depth, and is rectangular in cross section, measuring 23 feet by 13½ feet inside. The engine is a twin compound condensing Corliss, the high-pressure cylinders 16 inches diameter, the low-pressure cylinders 32 inches diameter, and the stroke 48 inches, driving direct two grooved drums of 7 feet diameter, with three grooves on each drum. The available steam



Cross Compound Corliss Winding Engine, by Messrs. Fraser & Chalmers Limited, as described in the Specification following.

pressure is 120 pounds on the square inch, and the load is 3000 pounds. A similar arrangement erected at Durban, in South Africa, consists of a twin Corliss engine, with cylinders 20 inches diameter by 48-inch stroke. Provision is made for compounding to be applied later; the drums are 8 feet diameter, expansion gear is capable of cutting off at anything up to one-fourth of the stroke, and the load is about 5000 pounds. At the De Beers Diamond Mines, in South Africa, the Whiting winding arrangement consists of a pair of vertical tandem compound condensing engines, having a maximum steam pressure of 120 pounds on the square inch; from a depth of 1250 feet the load raised at each operation was 9600 pounds of rock. The loading and unloading is effected automatically, and 92 windings have been made in one hour; on one experimental occasion 3665 tons were dealt with in 12 hours, the consumption of coal being 2¼ pounds per horse power per hour.

We are indebted to Messrs. Fraser & Chalmers Limited for the following specification of standard cross compound winding engines:—

SPECIFICATION

OF

STANDARD CROSS COMPOUND WINDING ENGINE.

(*See figs.* 366A *and* 366B, *sheets* 16 *and* 17, *between pages* 592 *and* 593.)

GENERAL.—To wind 4½ tons of coal from a depth of about 1670 feet. A balance rope is used; the maximum rope speed will be about 3900 feet per minute, equal to 78 revolutions per minute of the engine. It is understood that steam will be superheated. The cylinders will be built to stand 460 degrees F. total temperature; the engine will be heavy enough to work with 170 pounds boiler pressure.

BEDPLATES AND GUIDE SECTIONS.—Bedplates will be of massive design of the trunk type, bearing upon the foundations for the full length. The main bearing gap will be cast in, and will be fitted with four-part boxes of cast iron, babbitted. Side boxes, adjustable by wedges and screws; vertical adjustment may be obtained by inserting liners under bottom boxes.

Gaps will be of cast iron, babbitted, and provided with handholes for easy inspection of journals. The guide sections, also of massive design, will be bored out and faced at the same setting, so as to ensure exact alignment, and will be bolted to the bedplates and cylinders. The guides will be bored and scraped to a true surface. Oil trays are cast or fitted where necessary, to catch all oil and prevent same getting to foundations. The base of the main bearing will be of extra surface.

High-pressure cylinder, 32 inches diameter by 66-inch stroke, will be made of our best hard cold-blast iron, and will be fitted with a liner of the same metal forced in and further secured at each end by copper rings caulked into place. thus forming space for jacket steam. The liner is forced against a shoulder at one end, the other end being free to expand, and thus avoid all expansion strains and distortions.

The cylinder heads will be of cast iron, strong box section, and will be fitted with pop safety valves of ample area and Tripp's floating packing for piston rods.

The valve chambers will be cast in the body of the cylinder. The inlet and outlet valves will be of the Corliss type, double-ported, the exhaust valves fitted with shoes and springs and operated by one wristplate, thus providing a rapid opening to each valve. Steam valves are closed by vacuum dashpots, the point of cut-off being controlled by governor, the design of gear being such that when the governor is down the valves are not tripped at all, and the engine will be taking steam full stroke, and as soon as the speed increases, and the governor begins to rise, the valves will automatically trip and so control the speed. The range of cut-off will be from zero to 40 per cent of the stroke. The cut-off on high-pressure cylinder when up to speed will be about 15 per cent, and will not vary very much at any point of the wind. The inlet valves are so arranged that in case of over-pressure in the cylinders they will rise from their seats and act as relief valves of large capacity. This is in addition to the relief valves in the cylinder heads. The wristplates will be of cast iron, working on mild steel gudgeon pins of ample wearing surface. The rods connecting to valve gear will be fitted with wedge-adjustment gun-metal ends.

All pins in connection with this gear will be case-hardened and ground. The Corliss valves will be turned and ground perfectly true, the port edges machined to a straight edge.

Low-pressure cylinder, 53 inches diameter by 66-inch stroke, will also be jacketed and fitted with a liner, the design being similar to the high-pressure throughout; the heads and valve gear will also be similar.

The steam bonnets will be of cast iron, fitted with metallic packing; valve stems will be of steel; valve covers of cast iron, part polished and painted, presenting a neat appearance. Both cylinders will be mounted on cast-iron soleplates, so that they can be removed without disturbing the foundations at any time. The cut-off on this cylinder will also be controlled by governor, the adjustment being such that both cylinders will be taking steam full stroke at the same time, and when the high-pressure is cutting off the low-pressure will also be cutting off at such a point as to maintain a constant pressure in the receiver, or the work done in each cylinder kept equal at all points of the wind, as may be required.

A bye-pass valve will be fitted to each cylinder and connected to each end of same; these will be operated by one hand lever on platform.

Lagging.—Both cylinders will be lagged with planished steel of extra thickness, mounted with polished-steel angles and flats, and polished false covers where necessary.

Pistons and Rods.—The pistons will be of cast steel, strong box section; the high-pressure will be fitted with cast-iron rings, sprung into place; the low-pressure, with cast-iron rings, and a lining of Fraser & Chalmer's special piston babbitt.

The pistons are secured to piston rods by nuts forcing against a taper shoulder. The piston rods will be of mild steel, turned and polished, and secured to main crosshead by cotter.

Crossheads will be of cast steel, fitted with cast-iron wedge adjustment babbitted slippers. Crosshead pin will be fitted into taper bearing, ground into place and secured by nut.

Connecting rods will be of mild steel, finished bright all over, having solid ends, with wedge-adjustment cast-steel babbitted boxes for crankpin end, and gun-metal wedge-adjustment boxes for crosshead end.

Crank shaft will be of mild case-hardened steel turned from end to end, and will have a hole bored right through the centre 3 inches in diameter, which will be polished. The cast-iron part-polished and painted crank discs will be forced on both ends and keyed; the crankpins will also be forced into cranks.

Drum will be of the double-cone type, parallel part being 16 feet diameter by 6 feet 6 inches wide, each end of which is coned to a diameter of 12 feet

2 inches, and at this point drums will still further be extended on cone sufficient to take seven coils of rope, diameter at the outer end being 11 feet 6 inches. The drum will be built up, having cast-iron cheeks or arms of substantial section, in the rim of which will be formed the brake path and the groove cone part of drum. These grooves will be turned out to take 2-inch diameter rope.

At the outer end of this coil, rope will be carried through the drum rim and provision made for fastening at least one coil of rope on the internal part of the rim by means of a sufficient number of eyebolts. To these cheeks will be riveted the second cone part of the drum, which will be of mild steel plate ⅜ inch thick, to which will be riveted the parallel part of the drum, also of mild steel plate ⅜ inch thick; this latter lined with 4-inch oak. The two cones will have riveted to them an angle iron to take two and a half coils of rope. This angle iron will be riveted in such a manner as to properly take the rope from the grooves of the smaller cones and deliver same to the 16-foot part.

The whole drum will be stiffened and supported by heavy angle irons, and by rods from side to side. The cast-iron cheeks will each be made in halves, secured to each other by heavy shrinking rings and bolts, and are keyed to the shaft by two keys. The brake paths will be turned, and fitted with a liner of steel ⅜ inch thick, bolted on and turned, this liner being ventilated on the underside, so as to prevent, as far as possible, the heat generated by applying the brakes from extending to the drum cheeks.

Link Motion and Reversing Gear.—On each side will be supplied a link motion of the Allan straight-link type, having cast-iron eccentrics with cast-iron straps, all in halves; wrought-iron eccentric rods of flat section, painted and fitted with case-hardened and ground pins. The link of steel will also be hardened and ground. The link dye will also be hardened and fitted with case-hardened and ground pin. A heavy wayshaft will be supplied, mounted in cast-iron bearings, connecting the two link motions, and between the engine will be keyed a lever connecting to steam reversing engine.

Reversing Engine.—A steam reversing engine will be supplied complete, and mounted between engines, coupled direct to the above-mentioned lever. This reversing lever will have a steam cylinder and valve gear, fitted with a floating lever arrangement, which is suitably connected to piston and reversing engine, and consequently the link motion corresponds exactly to the position of the hand lever on platform. This engine will also be fitted with a water-cataract cylinder, which ensures steady motion and maintains a rigid hold upon the gear. This reversing engine will be lagged with planished steel; the covers will be polished, presenting a finished appearance.

Post Brakes.—A set of post brakes will be provided, the posts consisting of massive channel-iron beams, with cast-iron bracket ends, the lower ends mounted in substantial cast-iron base plates, the upper ends connected to each other by tie rod and suitable cast-steel levers. A steam brake will be fitted to these posts and will be of the Fraser & Chalmers standard design, which includes the Whitmore patent self-adjusting and variable-load appliance, the advantage of which is that it enables the driver to apply any desired load upon the brakes, ranging from zero to full load, according to the amount the foot lever is pressed down; this cannot be done with the floating gear alone. The gear also provides an automatic adjustment of the posts as the wood blocks with which they are fitted wear; this adjustment continues until the blocks are worn out. With this gear undue strains upon the engine and ropes, and flapping of ropes when brakes are applied, are avoided; the weight puts on the brakes, steam releases same; by this means the driver is not dependent upon steam to put on his brakes.

Governor.—A heavy Porter-type governor will be provided and mounted upon the foundation between engine, and driven by cut gearing. The governor begins to rise at about half the maximum speed, and continues to rise until the maximum speed is reached and the correct cut-off obtained. This governor is connected to the trip gear on both cylinders, as before mentioned.

Reheater Receiver.—This receiver will be fitted with wrought-iron tubes expanded into wrought-iron tube plates, the cylinder steam passing through

tubes, the reheating steam round same. A reducing valve will be supplied to admit steam at any desired pressure for reheating; a pop relief valve of ample area will be provided to prevent undue high pressure accumulating in same. A further reducing valve will also be fitted, which will admit boiler steam to receiver space.

CONTROLLING GEAR.—Channel-iron frame, with wood platform complete, will be provided, to be fixed on the left-hand side of the engine about one foot above floor level. On this platform will be mounted the necessary levers for controlling the engine, including one hand lever, machined bright, and fitted with latches working in a quadrant for operating throttles; one hand lever is similarly fitted for controlling reversing engine. A small hand lever will be fitted for operating bye-pass valves on high-pressure and low-pressure cylinder; a foot lever for controlling the brake engine. In connection with the reversing lever the Whitmore Patent Controller will be fitted. This controller is an appliance fitted between reversing lever and governor which ensures getting full steam against the engine at any time by reversing the lever; without this, supposing the engine was at top speed, and, for some reason, such as the upgoing cage breaking away, the engine would race away under steam, in which case it would be of no use reversing the lever, as the governor would not admit steam to the cylinder. It is to overcome this objection, and to ensure being able to get steam against the engine by the reversing lever, that this appliance is provided.

MOUNTINGS.—A double Grandison sight-feed lubricator delivering oil to the two-throttle valves; a Mollerup or other suitable plunger lubricator will be fitted to each side, worked from the engine, to feed the high-pressure and low-pressure cylinders; special nickel-plated oil box for main bearings and pump for returning oil to same on each side; special forced lubrication system for crankpins; tell-tale grease cups for eccentrics and other wearing parts; visible drop nickel-plated lubricators for guides, etc. Indicator reducing gear of a substantial design will be supplied complete, with pulleys for cord and indicator cocks and pipes; copper joint rings for all parts likely to be taken adrift; jointing material to complete the erecting; drip pans under steam bonnets; complete set of spanners; Geipel steam traps for jackets, and receiver drains complete with piping and valves connecting same. Cast-iron gauge plate, complete with the following:—7-inch dial nickel-plated gauges, one for high-pressure steam, one for intermediate steam, one vacuum, one for reheating steam in receiver. Thermometer pockets will be provided in the centre of the steam chest of each cylinder.

FOUNDATION BOLTS.—Complete set of foundation bolts, with hexagonal nuts and washers for top end and square nuts and strong cast-iron plates for bottom end, will be supplied for the whole engine, and a set of erecting drawings.

FRAMEWORK AND HANDRAILS.—Iron framework will be supplied for carrying the steam-reversing and brake engine and governor; also necessary handrails (polished) round cranks and drum, complete with floor stanchions.

DEPTH INDICATOR.—A depth dial indicator will be provided and mounted on high-pressure engine in a conspicuous position. Dial will be about 2 feet 6 inches diameter, having one pointer which will make not quite one turn for the whole depth. This is driven by cut gearing from crank shaft. A bell is fitted to signal at any point in the outward and inward wind.

SAFETY OVERWINDING DEVICE.—A safety gear will be supplied, consisting of a cast-iron column on which will be mounted two screws. On these screws will be threaded nuts which come in contact with certain levers which are connected to the governor throttle and to the brake engine, the action of this appliance being such as to quickly close the throttle and gradually apply the brake should the engine exceed its normal speed in any part of the wind; and further than this, should the engine be run slowly, and the driver by mistake omits to stop same when the cages are at the landing, the throttles are quickly closed by this device, and the brakes are rapidly applied, and so stop the engine within a few feet travel of the cage.

Our overwinding device is so arranged that it is possible at any time to put steam full on to the engine and ensure it being brought to a standstill without the aid of the engine driver before the cage reaches a dangerous position.

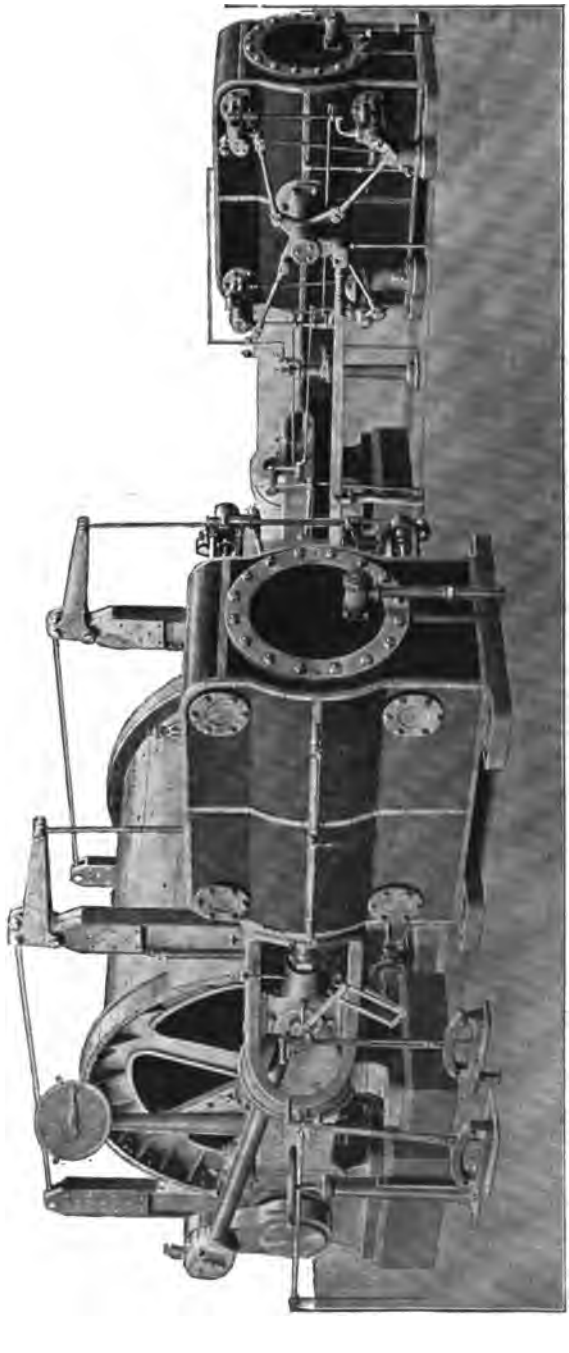
General.—The engine will be erected complete in our shops; cylinders, throttle valves, etc., tested under steam in our shops; and will be subject to the approval of the Company's engineer or his deputy. The material and workmanship will be of the best obtainable; all parts may be inspected during progress in the shops.

The engine will be thoroughly numbered before taking down to facilitate erection at the mine. All parts not machined will receive one coat of good oil paint, and parts polished covered with tallow; the parts liable to breakage will be suitably packed or crated. The services of a first-class erector will be provided.

SAFETY APPLIANCES.

We have elsewhere made reference to the appliances known as detaching hooks, or safety links, intended to prevent a cage being drawn over the headgear pulley, and, when detachment takes place in the headgear, preventing the cage from falling down the pit shaft. We mentioned that these appliances were excellent, and fulfilled a valuable purpose; but we also mentioned that they were limited in their action, they did not prevent an overwind, they did not stop the engine, and had no influence on the descending cage at all.

Suppose the engines to be running at a high speed, and, to make our illustration more striking, let us assume that the engineman, from some cause, loses control when going at full speed, which may be sixty miles an hour. There is no exaggeration in taking this speed as an illustration. Thirty years ago it was the practice at the Rose Bridge Collieries, Wigan, and is now accomplished at many important collieries in many counties. A maximum speed of sixty miles an hour probably does not represent more than an average speed of thirty miles an hour, and looked at in that way is less startling. The cage at that velocity would dash into the headgear with a force equal to that of a steam hammer of the same weight falling through one hundred and twenty feet vertical. The detaching hook might detach, and probably would detach, but the ascending cage and the descending cage would operate with uncontrollable force, and the mere detachment would be useless; and the engines might go on racing and accumulating force until they dashed themselves to pieces, and cast devastation all round. The real safety appliance is evidently one which will not content itself with acting *after* an overwind, but *will prevent* one, and will act upon the machinery so as to stop the whole arrangement before going too far. Starting in the wrong direction is



A PAIR OF CORLISS WINDING ENGINES.

Cylinders 26 inches by 54-inch Stroke; Drum 12 feet diameter. Built by Messrs. FRASER & CHALMERS to raise 4½ tons of Coal from a depth of 550 yards with Balance Rope. Steam 120 pounds.

much less important, because virtually no speed has been got up, and the maximum harm would be to overstrain the rope and break the pulley. The running away is a very serious matter, and it is a high tribute to the skill and care of enginemen that the occurrence is so seldom. Several years ago the attention of the writer was drawn to the safety appliance known as the "Visor," invented and patented by the late Mr. Alexander Bertram, and applied at many collieries in the Wigan district. Some years ago the writer was present at a number of experiments conducted at a Wigan colliery. The first series of experiments dealt with the case of winding engines being started the wrong way, and on the cage rising a few feet above the bank the visor acted and stopped the engines dead. The second series of experiments dealt with engines running away at full speed. After setting the engines in motion, the engineman left the handles, and the engines rushed on their mad career, attaining a cage speed of sixty miles an hour. At the appointed place the visor automatically came into action, and, shutting off the steam and applying the brakes, stopped the engines in about three revolutions. The distance in which the machinery is brought to a stand gives rise to two considerations. The first is that, so far as the engines only are concerned, that distance depends entirely upon brake power, and the brakes must not be too powerful, or the engines will be stopped too suddenly, and a serious breakage may result. The second consideration is that the ascending cage, by reason of its velocity, will rise a given height whatever the brake power may be, and to stop the engines in a less distance than that would be a source of danger, because the cage would continue to rise, slack rope would accumulate, and the cage falling back would exercise such a strain that the rope would break. At a speed of sixty miles an hour, if at any moment the engines were stopped dead, the cage would continue to rise one hundred and twenty feet, and at a speed of thirty miles an hour thirty feet. Under the ordinary conditions of winding the visor interferes in no way with the engineman and his work, and might be non-existent. It is a great reserve force, which acts only when the dominions of safety are invaded. An essential part of the mechanism is the governor arrangement, worked from the winding engines,

and this governor determines the speed at which the cage will be allowed to pass a given point. If the speed is exceeded a catch is automatically liberated, and falling weights apply the brakes and shut off the steam. The limit of speed is a determinable quantity, and the point of action can be fixed at will. The starting-the-wrong-way arrangement is no essential part of the visor patent, except in so far as when the cage gets too high it relieves the catch referred to regardless of speed. (*See fig.* 367, *sheet* 18, *between pages* 598 *and* 599.) The writer always appreciated the fact that so-called improvements which complicate winding engines, or interfere with the engineman's freedom of action, are neither to be desired nor recommended, and the same remark applies to appliances which may act when they should not, and provoke dangers they are intended to prevent. Safety cages were well enough when winding was slow and conductors were of wood, but are doubtful appliances for quick winding and wire conductors. There is a constant risk of safety cages which are affected by slack coming into action when they should not, and actually in this way causing the accident they are intended to prevent, and the dangers which they could deal with are fully preventable by good ropes. Suppose a rope does break and a safety cage does act, the rope itself, perhaps two or three tons in weight and several hundred yards in length, will fall upon the suspended cage, and destruction will mark its track; but efficient detaching hooks and appliances of the nature of the visor have the writer's approval, because they do not harass and do not complicate—they do not act when not wanted.

DETAILED DESCRIPTION OF THE VISOR.

Fig. 368 (*see page* 600) is an elevation of the principal portion of the apparatus; fig. 369 (*see page* 600) is a plan of the same; fig. 370 (*see page* 600) is a section on line XX (*see fig.* 369); fig. 371 (*see page* 600) is a central section (at right angles) to fig. 370.

A is the framework of the apparatus, which is secured in any convenient position; *B* is a rope, chain, or rod, connected with the lever or spindle of the throttle valve, and with the steam or foot brake, or both, through the medium of suitable mechanism, which has a constant tendency to close the throttle

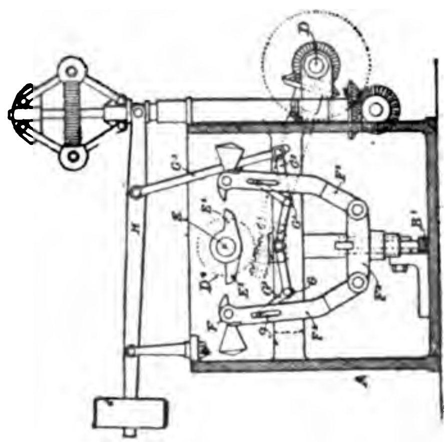


FIG. 870.

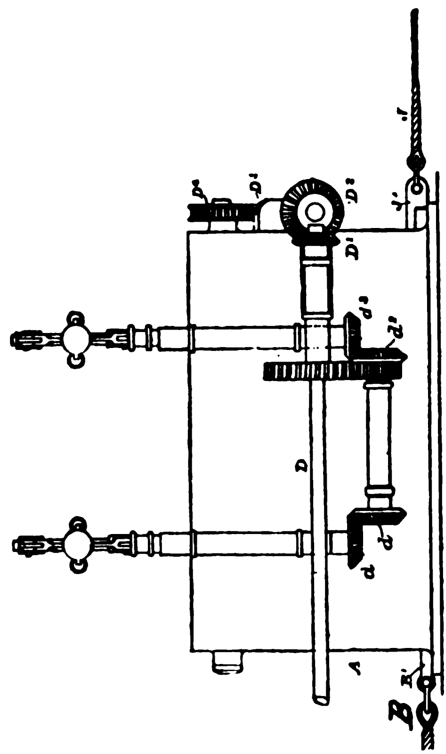


FIG. 868.

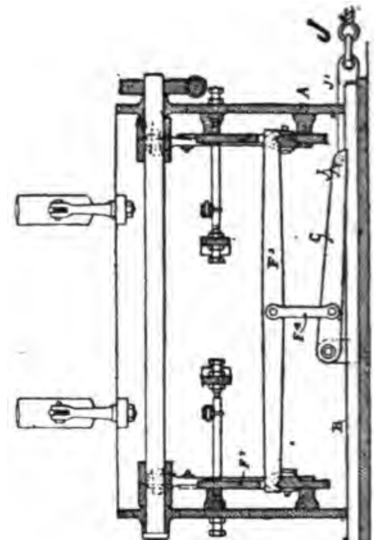


FIG. 871.

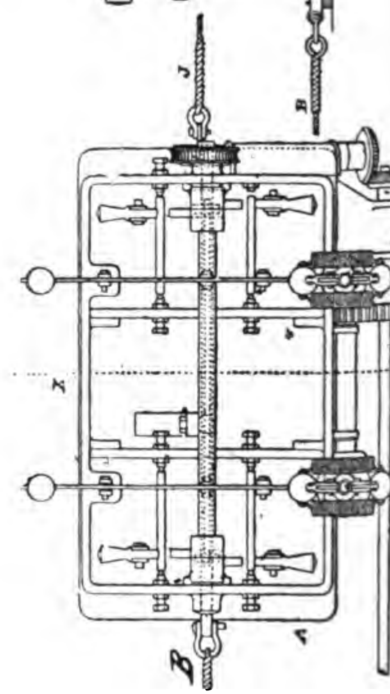


FIG. 869.

TO ILLUSTRATE THE CONSTRUCTION OF THE VISOR.

valve and put on the brake. The mechanism can, however, only become operative when the connection between the rope B and the framework A is severed. The rope B is attached to a sliding catch bar B^1 which is held in position on the framework by a pivoted catch or pawl C having its free end c resting in a notch in or against a shoulder on the bar. The bar B^1 is released as hereinafter described whenever the speed of the cage—that is, of the engine governor or governors—at a given point or points in its travel, reaches or exceeds a given amount.

D is a revolving shaft, which is connected on the one hand with the engine or winding drum, and on the other hand by means of suitable gearing D^1, D^2, D^3, D^4, with a revolving shaft E carrying one or more beaked cams E^1 according to the number of governors employed in the apparatus, that shown in the drawings being provided with two, set for different speeds. The gearing connecting the shaft E with the winding engine or drum is so proportioned that the beaked cams make one revolution during the travel of the cage between two given points. The governors are also preferably driven by the shaft D by gearing d, d^1, d^2, d^3. (*See fig.* 368.)

On each side of the beaked cam is a tappet or hook F, which is adapted to be engaged by one of the beaks when the governors are going at or beyond a given speed, the particular hook engaged depending upon the direction of rotation of the shaft E—that is, upon the direction in which the cage is travelling. The hooks are counterweighted as shown, and each hook is carried by an arm F^1, the two arms being kept apart by springs. The arms F^1 are pivoted to crossheads F^2, forming part of or connected with a rod or bar F^3 (*see fig.* 371), which is connected by a link F^4 with the pawl C. The bar F^3 may be counterweighted if desirable.

G, G (*see fig.* 370) are two rotable spindles, each carrying a bell crank lever G^1, G^1. One arm of each lever engages the arms F^1 by means of the slots g, and the other lever arms are connected loosely at their free ends, so that the movement of one lever is imparted to the other. One of the spindles G^1 carries an arm G^2, which is connected by a link G^3 with the counterweighted governor lever H. By this mechanism the arms are moved inward simultaneously, as the speed of the governor increases.

The mode of action of the apparatus is as follows: When the engine is going below a given speed the hooks F are not moved into the path of the beaked cams, but when the engine attains or exceeds a certain given speed the governor or governors rise, and the eccentrics or levers G^1 are turned upon their pivots, and the hooks are placed in the path of the beaks of the cams E. One of the beaked cams will now catch a hook, F, and raise it, provided the cams are in position corresponding to the given point or points in the travel of the cage. The hooks being raised, the arms F, crossheads F^2, and the bar F^3 are raised also, and the pawl C is disengaged from the catch bar B^1, and the latter and the rope B released so as to apply the brake and shut off steam, as before described. If, however, the governor slackens in speed before the beaked cam arrives at one of the fixed positions, the hooks are drawn back, and the cam passes them without coming in contact with them.

J is a rope chain, or rod, which is connected at one end with one or more tappets or levers projecting in the path of the cage, or other moving part having the same relative motion as the cage. The other end is attached to a sliding catch bar J^1, having an inclined surface, j, which rests below a pin or projection c^1 on the other end of the catch or pawl C, so that the latter is disengaged from the catch bar B^1 when the bar J is drawn outwards. When the cage or its equivalent strikes one of these tappets the rope J is pulled, the catch or pawl C released, and the stop valve closed and brake applied independently of the speed at which the cage is going. This latter arrangement may be employed either in conjunction with or independently of the beak cam and governors and the mechanism connected therewith.

From this description it will be noticed that so long as the engineman keeps his engines under proper control, and does not come too fast when nearing the top, the visor does not interfere, but should he keep steam on too long, and the speed be kept too high when it should be lowered, then the visor steps in, shuts the steam off, and applies the brakes. The engineman, to put it in another way, starts the cages and applies full steam, in due course he shuts it off, and the engines slacken speed and come to rest. If he had not shut steam off at, say, the fifth stroke from the top, the visor operating at, say, the third stroke

from the top, if the engines are going faster than they should go at that particular point, immediately steps in and arrests the engines by shutting off steam and applying the brakes. The speed of the engine is again controlled by the visor within a stroke or so from the top, when the speed should necessarily be still slower than at the third stroke, and with the same results.

As a still greater security, an arrangement has been added in the headgear whereby, in the event of the engines being started the wrong way, or of the engines creeping, or a slow overwind taking place, the stopping mechanism attached to the visor is actuated, and the brakes applied. This takes place independently of velocity. The visor depends for its action on velocity, and while it will not stop a slow overwind it will certainly stop a fast one. The visor merely liberates the arresting mechanism to do its work, and on the power of that mechanism depends how soon the engines will be arrested.

It does not interfere with the engineman in any way, nor with the output. The engines may go as fast as they will up to a certain point, after that it takes notice, and is ready to interfere if required, but not otherwise.

It safeguards both ascending and descending cages, and will reduce the speed of the cages and render the action of safety hooks tolerably certain if the brakes are not of sufficient power to stop the engines entirely.

It can be readily and cheaply applied to all classes of winding engines, the cost depending in some measure on what is necessary to be supplied to drive the machine and actuate the levers of steam valve and brakes.

It can be made to shut off the steam, apply the steam brake, apply the foot brake, unnotch reversing lever, and bring it to midgear, open relief valves of cylinders, close valve in exhaust pipes, or all of these if required.

With the visor applied to prevent a fast overwind, and the arrangement in the headgear to prevent the engines being started the wrong way, and reliable detaching hooks, disastrous overwinding becomes almost an impossibility.

ENDLESS-CHAIN WINDING.

Before leaving the subject of winding and winding engines, we may briefly refer to the system of winding—already mentioned in the chapter on "Haulage"—by endless chain.

The arrangement is well represented in fig. 372 (*see sheet* 19, *between pages* 604 *and* 605), and fig. 372A, the former of which gives two elevation views and the latter a plan view. A small pair of horizontal engines supplies the necessary motive power, and by means of a chain-drive and gearing operates a pair of large sprocket wheels erected vertically over the pit shaft.

The sprocket wheels work what might be described as two gigantic bicycle chains—each, of course, being endless and hanging vertically in the shaft—passing round pulleys at the bottom. The chains are kept steady by the pulleys, which are,

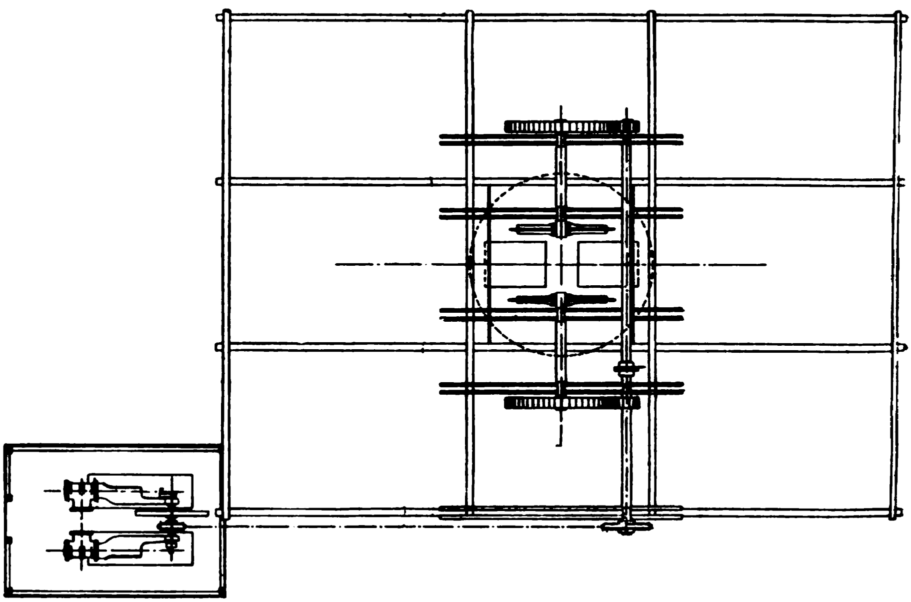
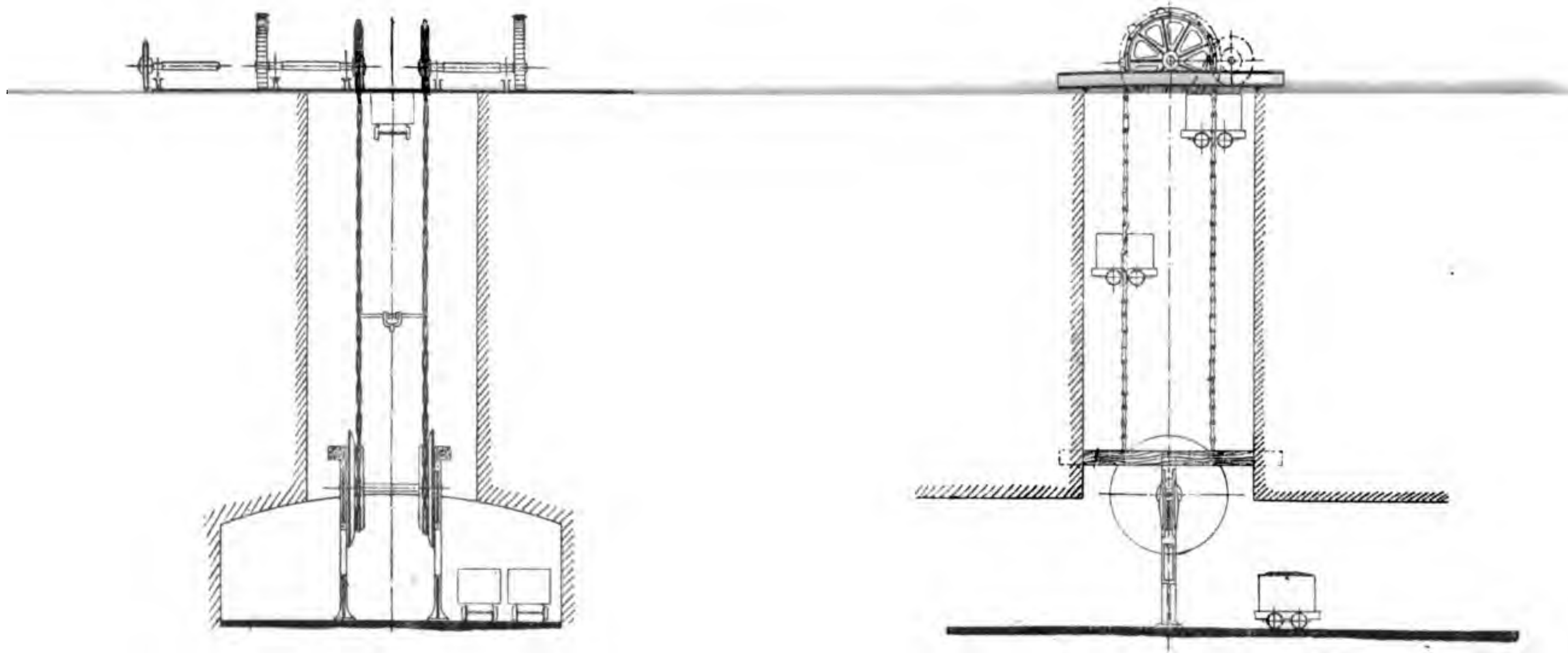


FIG. 372A.
PLAN OF ENDLESS-CHAIN WINDING GEAR.

as a matter of fact, supported by the chains, the axles being free to move vertically in the slidebars shown in the illustration. At regular intervals horizontal bars connect the two chains, and to these bars the tubs are attached, being suspended singly in the manner shown.

The arrangement answers well enough for shallow pits, and in the East Lancashire coalfield, where, as we have already remarked elsewhere, the endless chain reigns supreme, some excellent examples are in operation.

SHEET 19.



ELEVATION. ELEVATION.

FIG. 372.—ENDLESS-CHAIN WINDING GEAR.

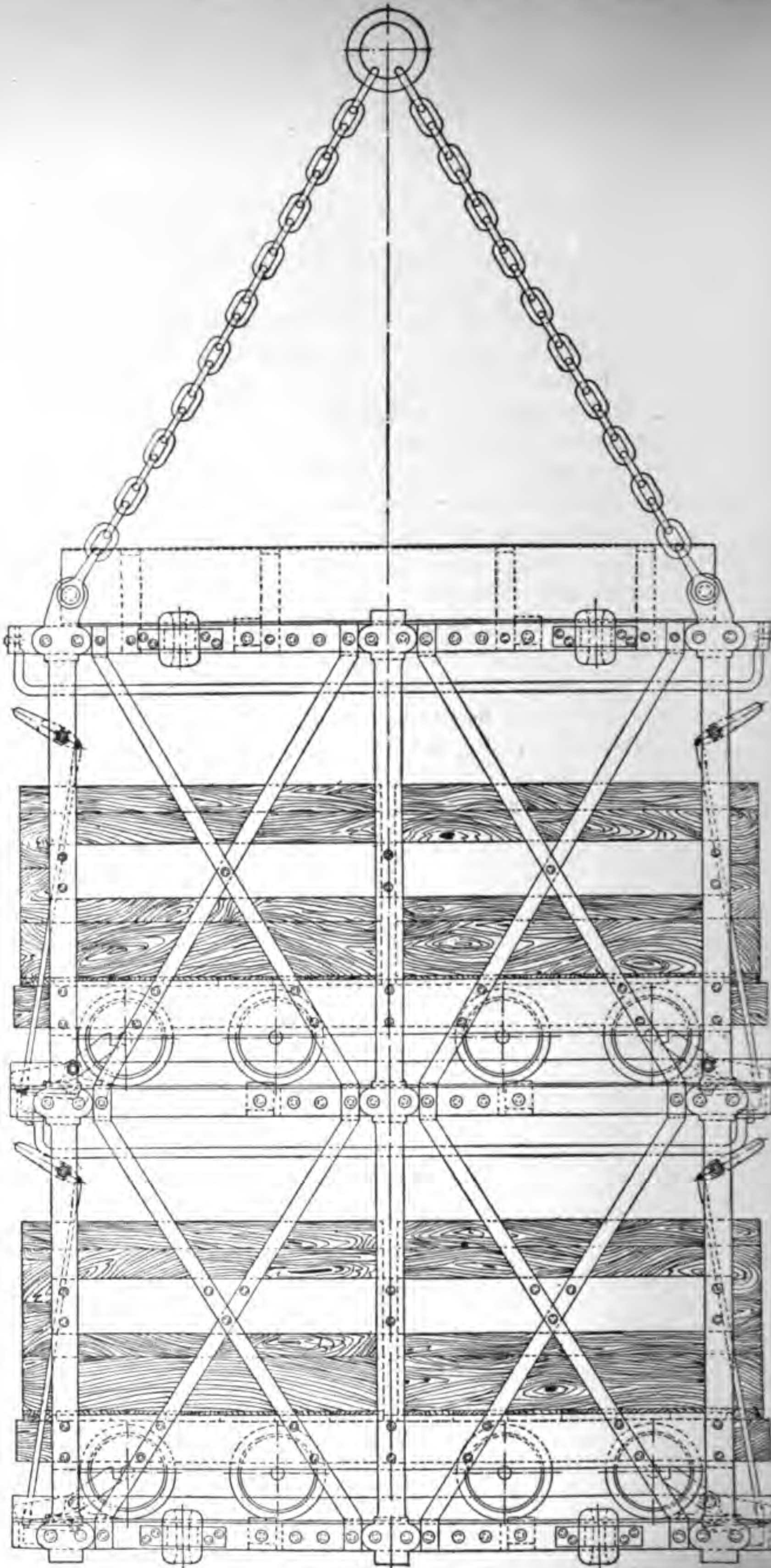
The balancing of the load is as nearly perfect as possible; indeed, the load is made up of the weight of coal and the friction only. The chain balances itself, the tubs are balanced, the coal alone represents the unbalanced load.

On the other hand, the chains are very heavy; the breaking of a link is a serious matter. The speed is slow, and although a fair output can be maintained from a shallow pit, a large output is clearly impossible, and the system is quite inapplicable for shafts of even moderate depth.

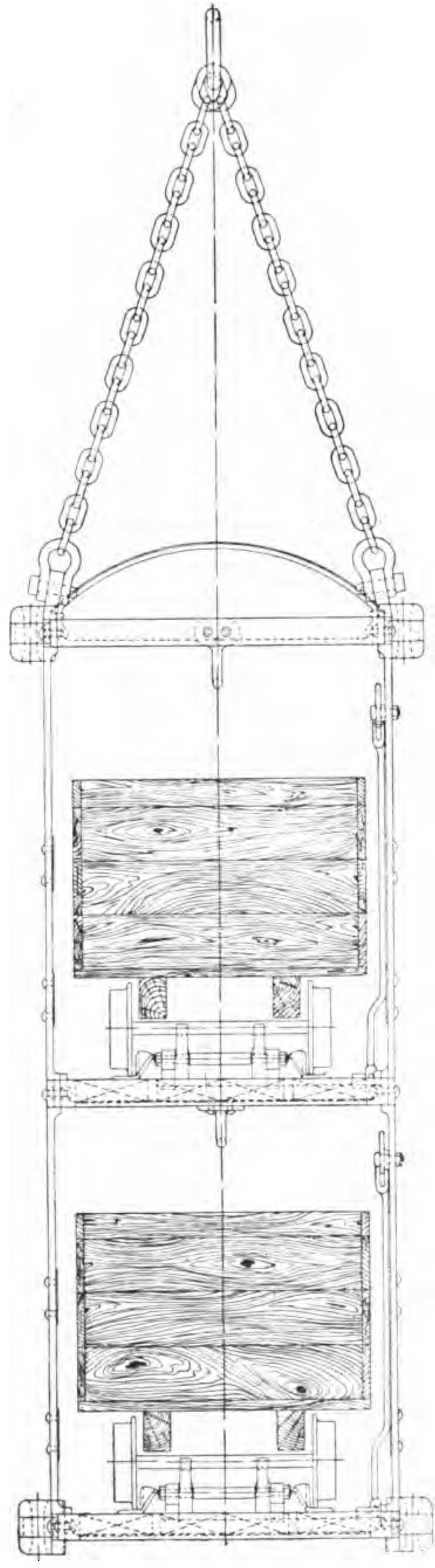
The tubs shown in the illustration are six hundredweights' capacity, anything larger or heavier would be difficult to handle at the pit bank, where they have to be pulled on to the landing plate and detached from the chain. The latter is in continuous movement at such a speed as to deliver four full tubs in rather more than a minute (65 seconds).

A separate pair of winding engines, headgear, and shaft is required for raising or lowering men, and these engines are practically idle except when men are being raised or lowered.

Endless-chain winding is not introduced here as an example of recent developments in winding, and it is not likely that its application will extend as time goes on.



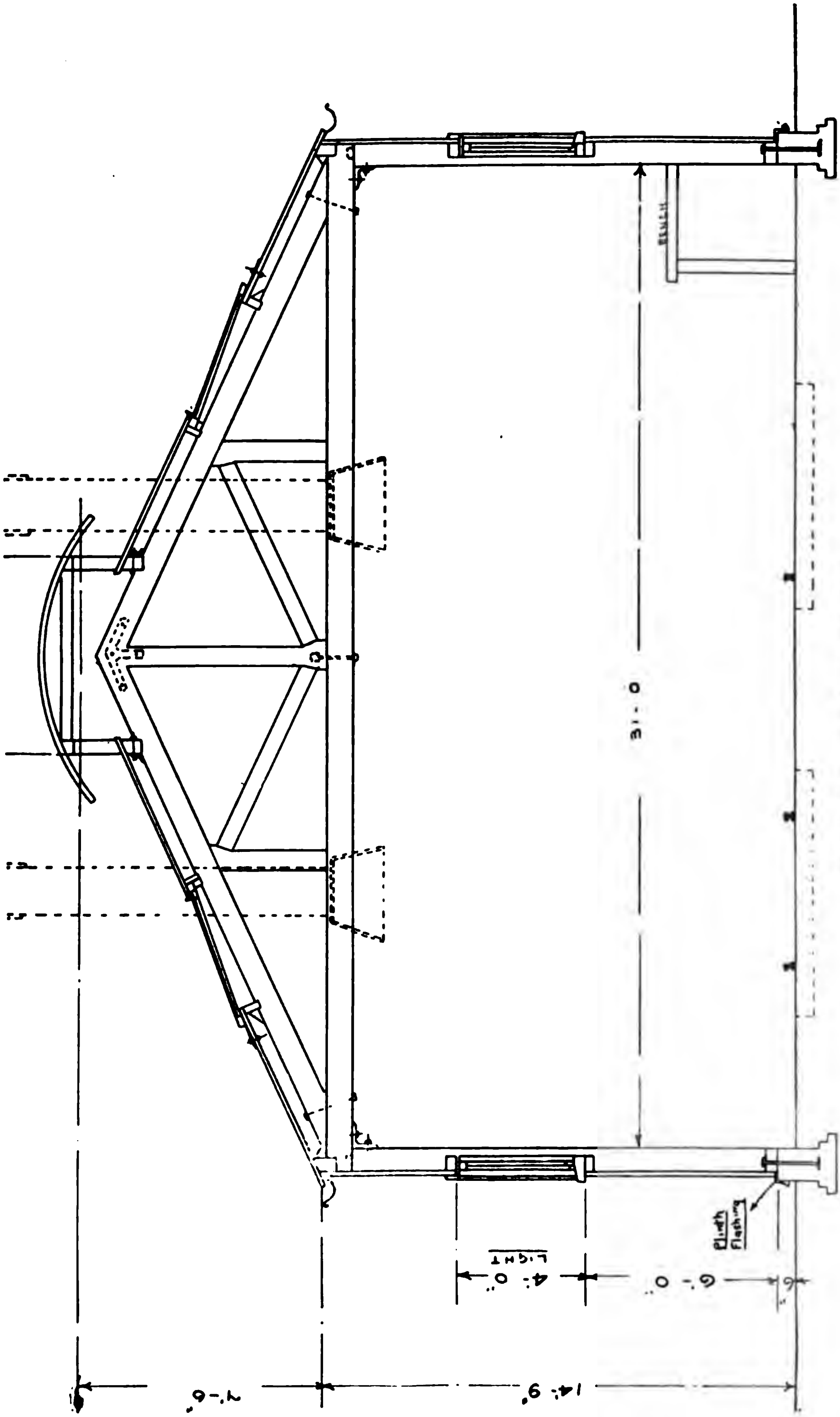
Showing a Double-Decked Steel Cage for Four Tubs.



CHAPTER XIII.

DEALING WITH COAL AT BANK.

THE efficiency in colliery operations includes as an important element the arrangements by which, on reaching the pit bank, the coal is despatched as expeditiously and as properly as may be to the particular point of sale, which may be by means of road, or rail, or water. Our forefathers had their difficulties, no doubt, in connection with mining operations, and had to meet the dangers peculiar to their times; but they certainly did not harass themselves with arrangements connected with the manipulation of the coal, either in the mine or at the surface. Underground they separated the round from the small, and left what they called the slack in the mine, causing the loss of a very great deal of valuable coal, and laying up a certainty of disastrous mine fires. On reaching the surface the coal was dumped into carts, or wagons, or boats, and forwarded to its particular market. The only arrangement that appeared to be necessary was that a cart road, or a railway siding, or a canal, should pass the colliery. But as time went on it became evident that such methods were extravagant to a degree, and that some system was necessary, and proper surface plant had in this way an introduction. The position of the surface arrangements at a colliery must, of course, be affected to a very great extent by the seams of coal to be worked, the pit shafts being placed in the best possible position in connection with the coal areas; and also in a good many cases taking into consideration the water-making capabilities of the mine. The surface plant surrounds the top of the coal-winding shafts, and may or may not be in proximity to a main line of railway, a canal, or a river. That does affect the transit to and from such outlets, but does not materially affect the actual colliery surface



SECTION OF COLLIERY LOCOMOTIVE SHED.

arrangements. A good deal of thought and skill have been directed to the arrangement of the plant at certain collieries with much advantage to the working, and, on the other hand, a good deal of mismanagement has been displayed, and the result has been a serious obstacle to the working. The railway arrangements belonging to the colliery itself should be such as give convenient communication with the various parts of the establishment; they should be such as will conveniently bring all materials to the colliery, and with equal convenience take all materials away. The various lines should have such an inclination in favour of the load that the wagons by gravitation will move to the points required and pass away from the points required, say 1 in 75. Horse haulage should be avoided, and there is probably no better means of bringing wagons in or taking wagons out than the locomotive, which, being used almost altogether for what we may call shunting operations, can be of a compact tank type with a short wheel base capable of passing round sharp curves.

What we call capstan engines (*see figs.* 356 *and* 357, *pages* 568 *and* 569) are for the purpose of enabling repairs in the pit shaft, either connected with the shafts themselves or their contents, and they are small engines so arranged with gearing that they can deal with a very considerable weight quite safely, either to raise or to lower. The space between the pillars of winding engines may be used for the accommodation of the capstan engines. The location of the steam boilers should, so far as possible, be such as to avoid any considerable distance to the engines to be supplied, and every convenience should be afforded for the delivery of fuel to the boilers, so as to prevent the necessity of so much loading and unloading.

Still embarking on what may be termed these preliminary remarks, it will be well to refer to the arrangements more in detail. When the screening of coal was first taken in hand it was mostly done by passing the coal over fixed screens, the bars of which were rectangular in section and had no movement. They were so arranged as to afford slots the full length, the width between the slots being arranged according to the size of coal intended to pass through. Fig. 373 and fig. 374 (*see page* 612) represent very fairly a screening arrangement of the days to which we have been referring; figs. 375 and 376 (*see page* 613) illustrate the progression of these fixed screen bars. A, in fig. 376, was the type introduced

by the writer. What was wanted was simply to separate the coal coming from the pit into two sizes—namely, coal and slack. The colliery proprietor was becoming less

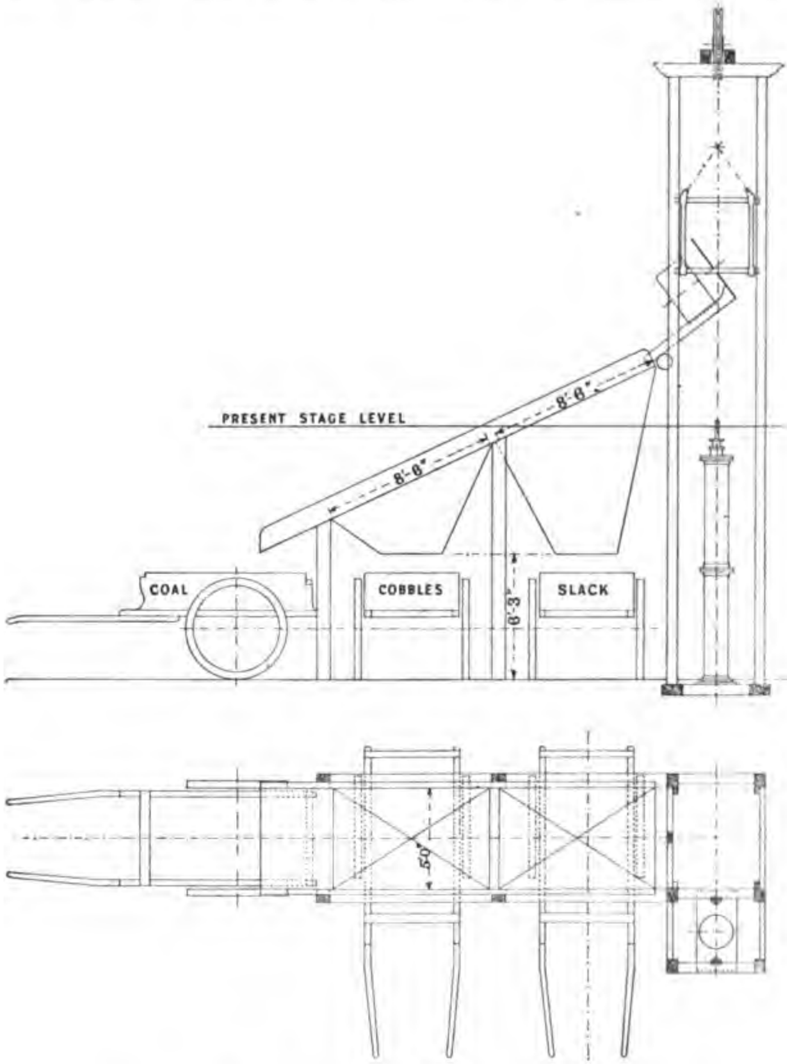


Fig. 373.
Showing a Fixed Bar Screening Arrangement with Steam Hoist.

enamoured of leaving the slack in the mine. If screening was to be done at all, it ought to be something like

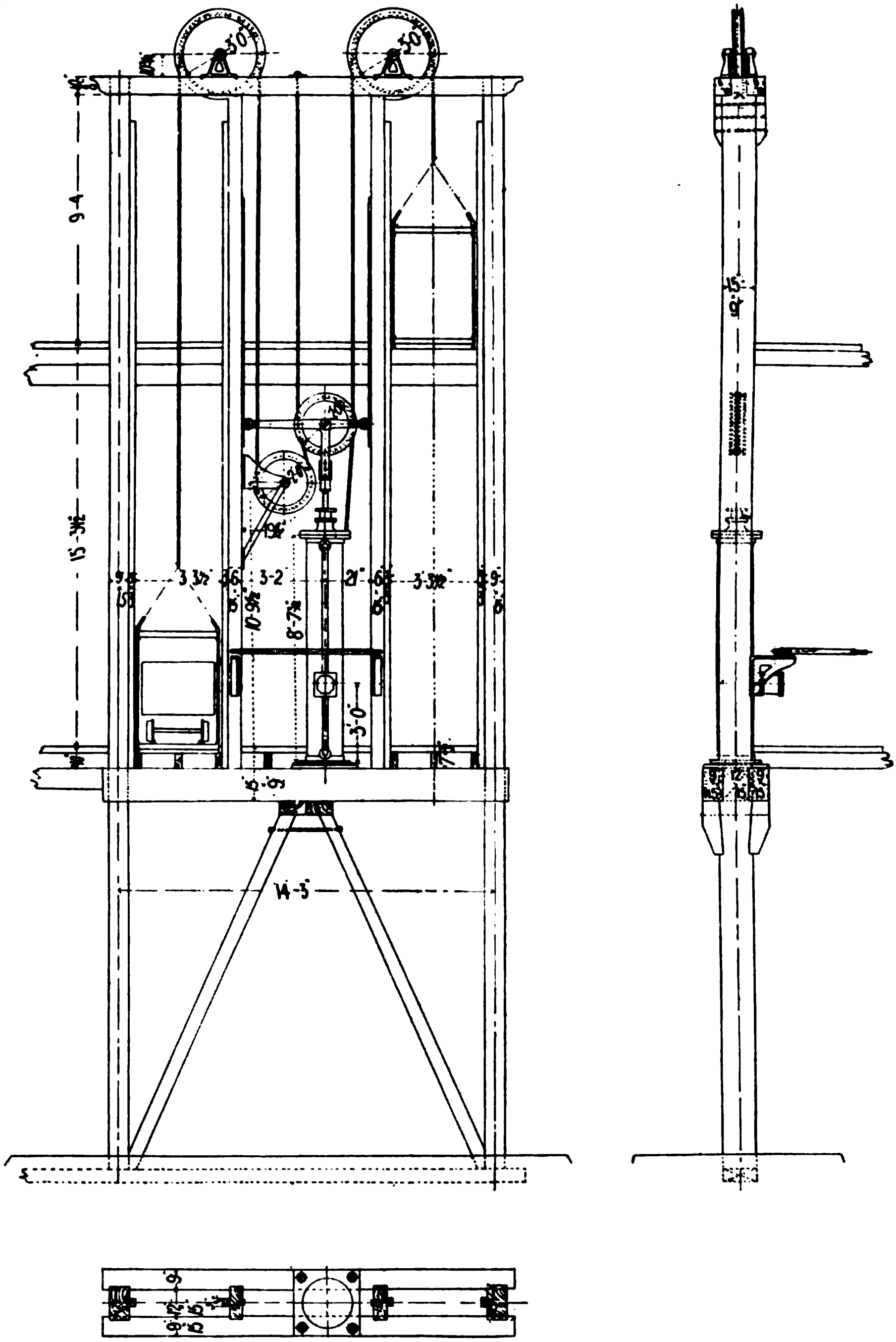


Fig. 374.

Arrangement of a Double-Cage Steam Hoist to Raise Full and Lower Empty Tubs.

efficient, because if round coal got amongst the slack the colliery proprietor was doing injustice to himself; if slack got amongst the round coal the customer was receiving something of less value than he was paying for. The flat-topped bars in figs. 375 and 376 could not avoid carrying forward slack with the round coal, nor

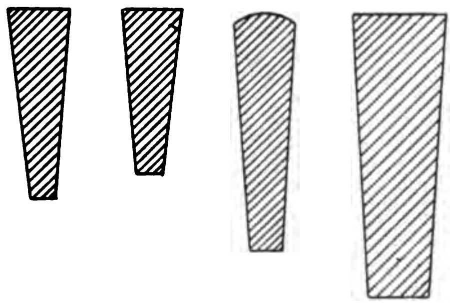


FIG. 375.
SECTION SHOWING TYPES OF SCREEN BARS.

could they avoid the spaces becoming choked; the bar **A**, in fig. 376, carried forward no slack with the round coal, and the spaces did not become choked. These fixed screen bars were mostly made of cast iron, but steel was found to be much better. The roughness of the slack—namely, whether it should pass through half-inch or one-inch or two-inch spaces—was regulated by the combs in

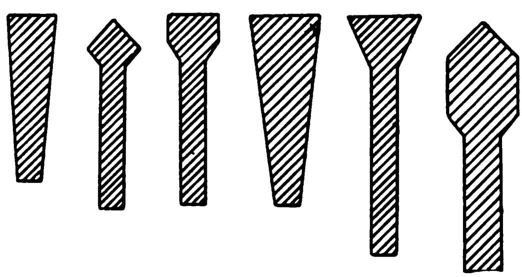


FIG. 376.
SECTION SHOWING TYPES OF SCREEN BARS.

which the bars were fixed, and which on their four sides had a different mesh. (*See fig.* 377, *page* 614.) Even in the comparatively early days there was an arrangement by which the screening of the coal was further developed. The slack, after passing through the fixed screen, was mechanically conveyed to a height of some fifteen or twenty yards, and discharged into a revolving

riddle about four feet diameter and some ten or twelve feet long, with open ends, and built up of circular rings, and bars about one inch square running lengthwise of the riddle. This appli-

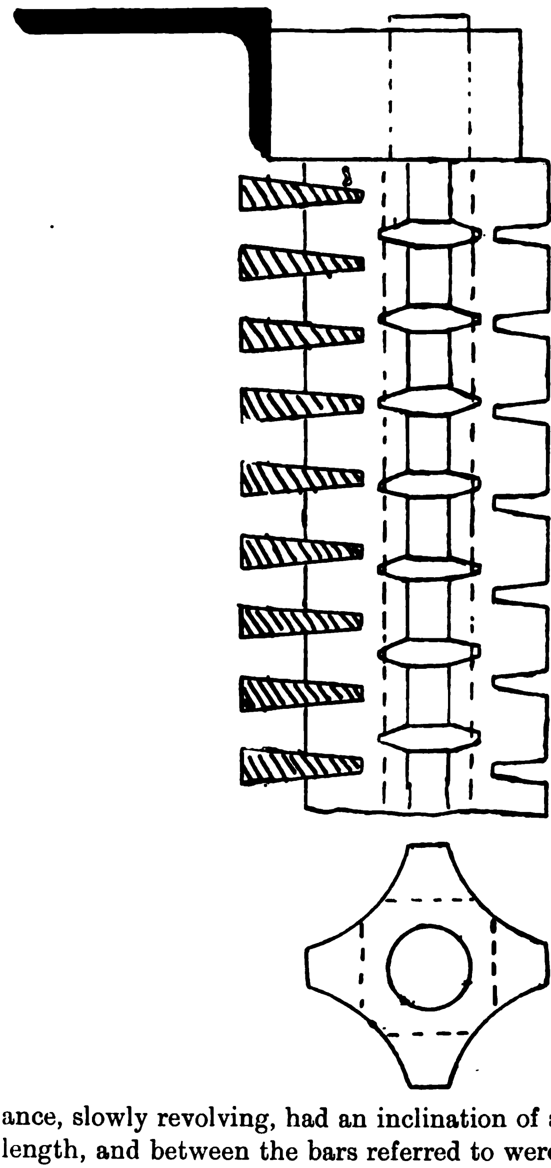


Fig. 877.
Section of Fixed Bar Screen, with Comb for Adjusting the Space between the Bars.

ance, slowly revolving, had an inclination of about a foot in its length, and between the bars referred to were spaces of about a quarter of an inch. The round portion of the slack passed

forward through the end of the riddle and constituted the coal known as "nuts," which always brings a good price. The fine portion of the slack passed between the bars of the revolving riddle and became the fuel used in the manufacture of coke, in which smallness is a virtue.

So far we have dealt with what may be termed the first stage in the development of colliery surface arrangements for dealing with coal. The pit banks were, in the majority of

FIG. 378.
SHOWING ELECTRICALLY-OPERATED PICKING BELTS AND COVERED-IN PIT BANK.

cases, not covered; the cages had all to be unloaded and loaded by manual labour; the same power had to convey the boxes from the cage to the screen, and from the screen to the cage; there was no mechanical contrivance upon the pit bank, or connected with it, except perhaps a small hoist used for communicating between the railway level and the pit bank; the appliances for discharging the coal from the boxes into the screens was also an effort altogether manual. What do we

find now? A pit bank is an enclosed establishment, although it took our colliery authorities a long time to realise that their workpeople could work better protected from the elements than unprotected, and that the coal was in a much better condition for manipulating when dry than wet. (*See fig.* 378, *page* 615.) The cages come to bank, and it is not too much to say that in the future that will be the rule, which is even yet more or less of an exception—namely, to load or unload mechanically, and all the decks at one level, made possible by lifts, which, after receiving the contents of a cage, or an imitation cage, are manipulated in the interval occupied by a winding. Even now a very general arrangement is, that the box immediately on leaving the cage is taken in charge by a creeper, which conveys the box to the tippler; that, in its turn, operates mechanically, and after discharging each box hands it over again to another creeper, the journey being completed by delivery to the cage.

The construction of the creeper is illustrated in fig. 379, and its application is indicated in figs. 315 and 316 (*see sheet* 13, *between pages* 522 *and* 523), and fig. 321. (*See sheet* 14, *between pages* 526 *and* 527.) It may be convenient at this point to refer to these two illustrations to follow out the operation of banking, screening, and loading the coal.

In both cases the loaded tubs, as they leave the cage, gravitate towards the tipplers, passing over the weighing machine on the way. Leaving the tipplers, after depositing their contents on the screens, the tubs proceed, still under the influence of gravity, to the foot of the creeper, which raises them to a sufficient height to enable them to run through to the shaft, or to a convenient position close to the shaft, for reloading into the cage.

An alternative arrangement is that in which the creeper deals with the loaded tubs immediately after the weighing process, elevating them sufficiently to enable them to run by gravity right through to the tipplers, and afterwards back to the shaft.

The action of the creeper is exceedingly simple. The tubs run to the foot of the creeper, and are caught by a pair of the projecting links on the twin endless chain, which bear against the front axle of the tub. The speed of the chain is about

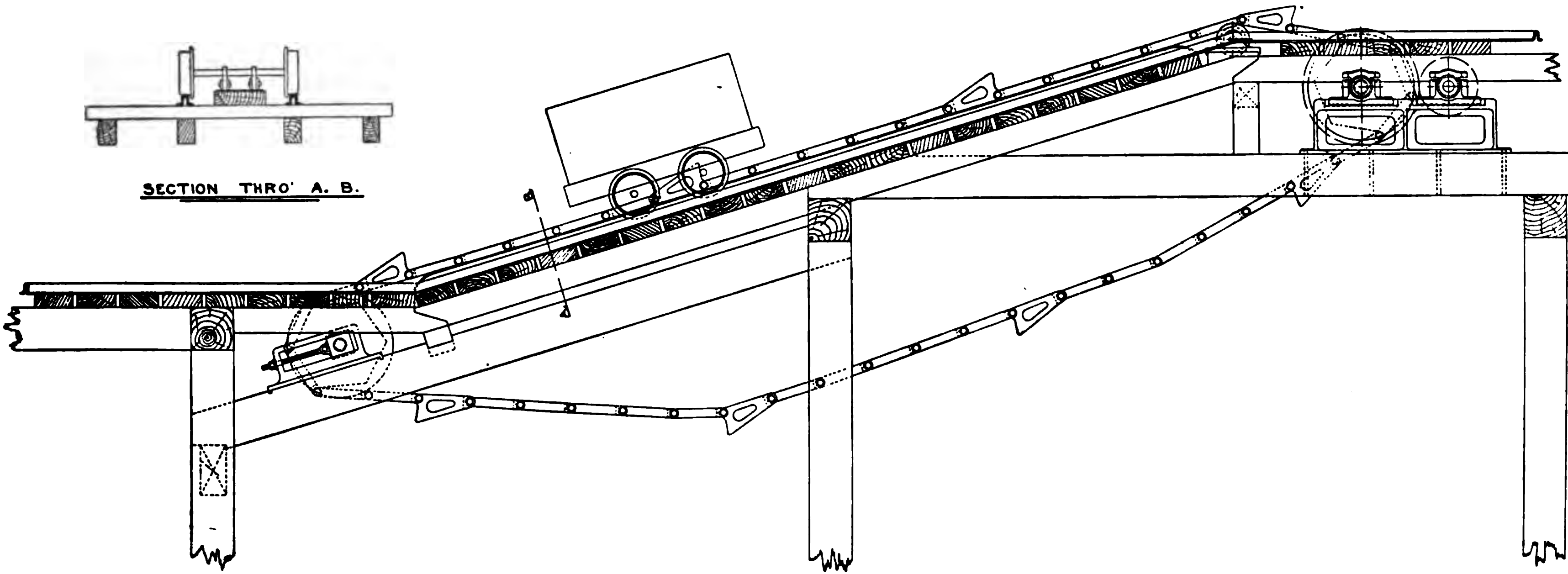


Fig. 879.

Arrangement of Creeper to convey the Tubs to the Top of an Incline, whence they run by gravity to the Tipplers, or elsewhere, as required.

sixty feet per minute, but this can, of course, be arranged to suit the local requirements.

TUB CONTROLLERS.

In connection with the creeper an almost indispensable appliance is the tub controller. We have already illustrated

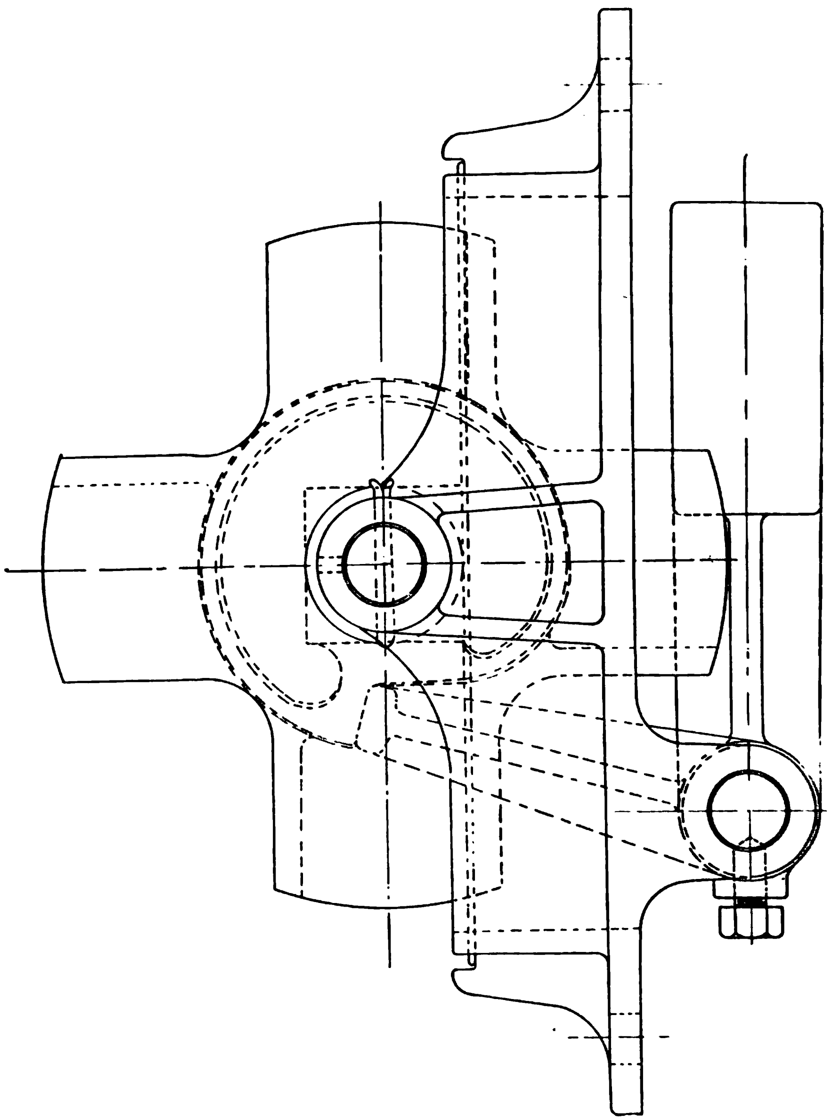


FIG. 380.—MCBEAN & EATON'S TUB CONTROLLER.

McBean & Eaton's tub controller (*see fig.* 246, *page* 411) and the further illustrations, figs. 380 and 381, will enable our readers to follow its action.

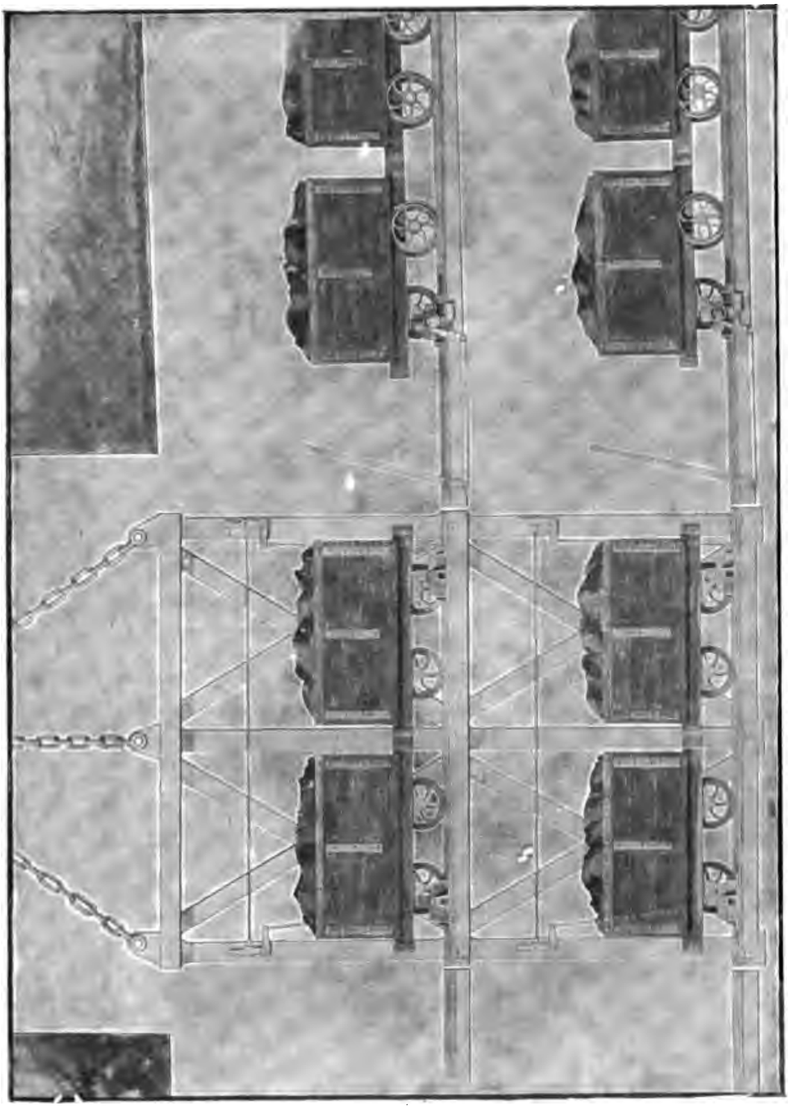


FIG. 381.—SHOWING MCBEAN & EATON'S TUB CONTROLLER APPLIED TO CAGES AND IN USE AT THE PIT BOTTOM.

The controller is intended to be fixed in a convenient position to intercept the tubs as they gravitate down the

inclines in connection with the creepers, etc. Its object is to arrest the progress of the tubs, and enable the attendant at the cage or at the tippler, as the case may be, to release them, say two at one time, without leaving his post. It will be observed that the controller consists of a pair of wheels, having four large teeth or projections, which, projecting sufficiently high above the rail level, come in contact with the axle of the tub. The direction of rotation, as seen in fig. 380 (*see page* 618), is counter-clockwise, but, as shown in the figure, rotation is impossible, because the flat shoulders on the cams (shown in dotted lines), which form part of the star wheels, rest against the end of the lever or stop. This lever can be withdrawn by a handle fixed some distance away, in any convenient position, when the incline causes the tubs to run, each successive axle giving a quarter turn to the star wheels.

When a complete revolution has been made, two tubs having passed over the controller, the shoulders on the cams again come in contact with the stops, and the movement of the remaining tubs is arrested until the handle is again worked.

The tub controller is one of the many simple time and labour-saving appliances which have done so much towards increasing the output and decreasing the cost of handling coal on the pit bank, and is to be found in operation at most modern collieries.

Fig. 381 (*see page* 619) is intended to represent the controller applied both as a tub stop in the cages and to assist in loading the cages at the pit bottom. To load the cage the handle shown in connection with each deck is operated, and also the lever working the fixed controller. It will be observed that fig. 381 illustrates the arrangement of simultaneous decking with two levels or platforms. The loaded tubs, released from the controller, run into the cage, pushing out the empties. When two tubs have entered the deck, the cage controllers automatically lock and secure them, at the same time the fixed controllers arrest the further movement of the loaded tubs waiting to be loaded into the cage.

TIPPLERS.

The old-fashioned self-acting end tippler, which overbalances when a loaded tub is in position, and deposits the coal over the narrow end of the tub, after falling a considerable

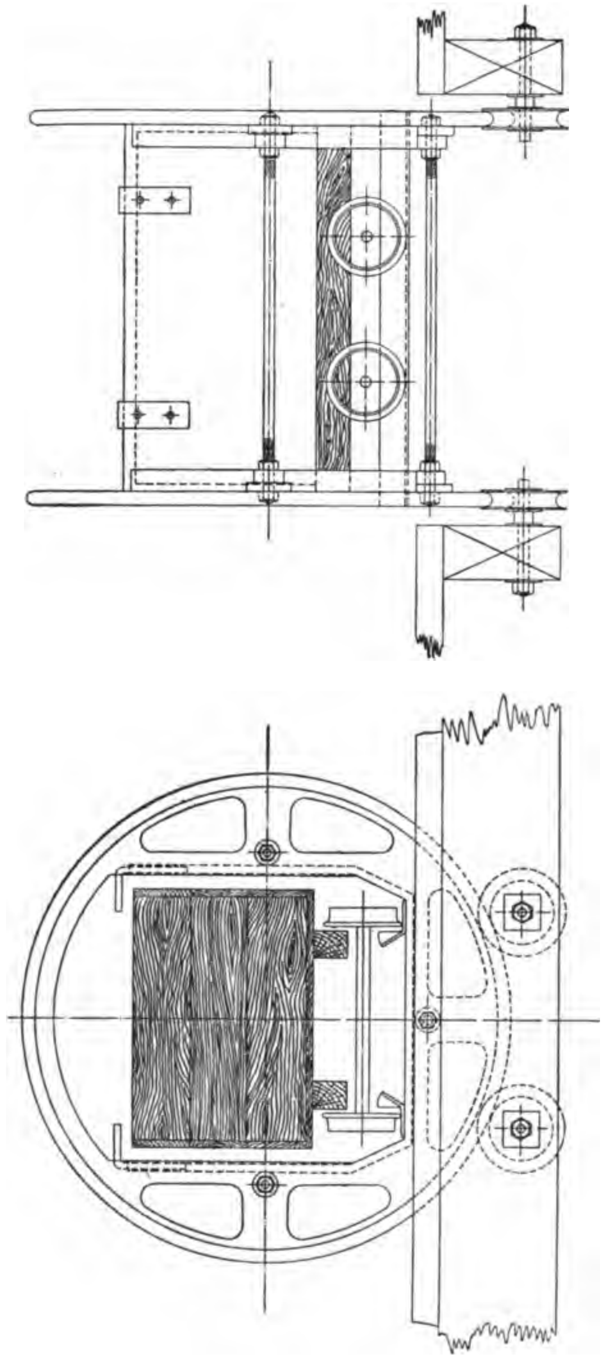


FIG. 382.—SHOWING A HAND-WORKED SIDE TIPPLER.

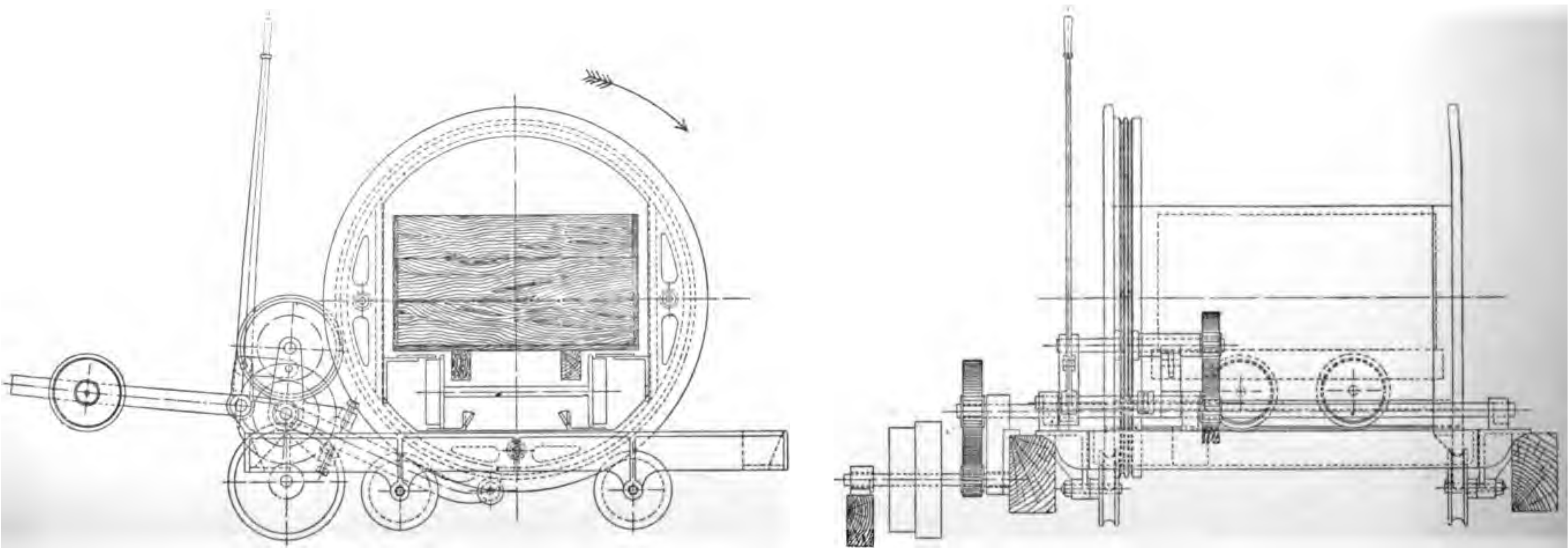


Fig. 888.—A Power-Driven Side Tippler.

distance, rarely finds a place in the modern pit-bank equipment. These end tipplers are first-rate time wasters, since each and every tub has to be withdrawn the same way it entered, and each tub has to wait until the one preceding it has been withdrawn.

The side tippler (*see fig.* 382, *page* 621, *and fig.* 383) avoids all these objections. The coal has not so far to fall, and the breakage of coal is therefore less. The coal is distributed more evenly over the screening surface, being tipped over the broad side instead of the narrow end of the tub, and as soon as one tub is empty it is pushed out by the next succeeding full tub, which immediately takes its place.

Side tipplers are either power-driven, actuated by the same engine or other motive power that works the creepers, belts, etc., or work by gravity. In both cases they are usually automatic—that is, having been set in motion they continue to revolve until the emptied tub assumes its upright position, when the tippler is automatically stopped, and the empty tub is pushed out by the succeeding full one. Figs. 383 and 384 (*see page* 624) illustrate respectively a power-driven tippler and a four-box gravity tippler, made by Messrs. John Wood & Sons Limited, of Wigan.

The latter, the four-box gravity tippler, is an ingenious contrivance, which has been extensively applied; it will be found in several of our illustrations of pit-bank arrangements. It is self-acting, simple in construction, and well adapted for dealing with a large quantity of coal, especially soft coal, as there is practically no fall, and breakage is reduced to a minimum.

The tippler is operated, as shown in the illustration, by a foot lever, which releases the catches; the full box then descends and is controlled by a hand brake, until stopped by the catches, which automatically fall into position after being released.

Since this illustration was made the operating gear has been remodelled, and both catches and brake are now under the control of one hand lever. Some of the power-driven tipplers are so contrived that the first half of the rotation, whilst the tub is being emptied, is comparatively slow, but the latter half, when the tub is empty, is performed in much less time, the tippler being driven more quickly until automatically thrown out of gear and stopped.

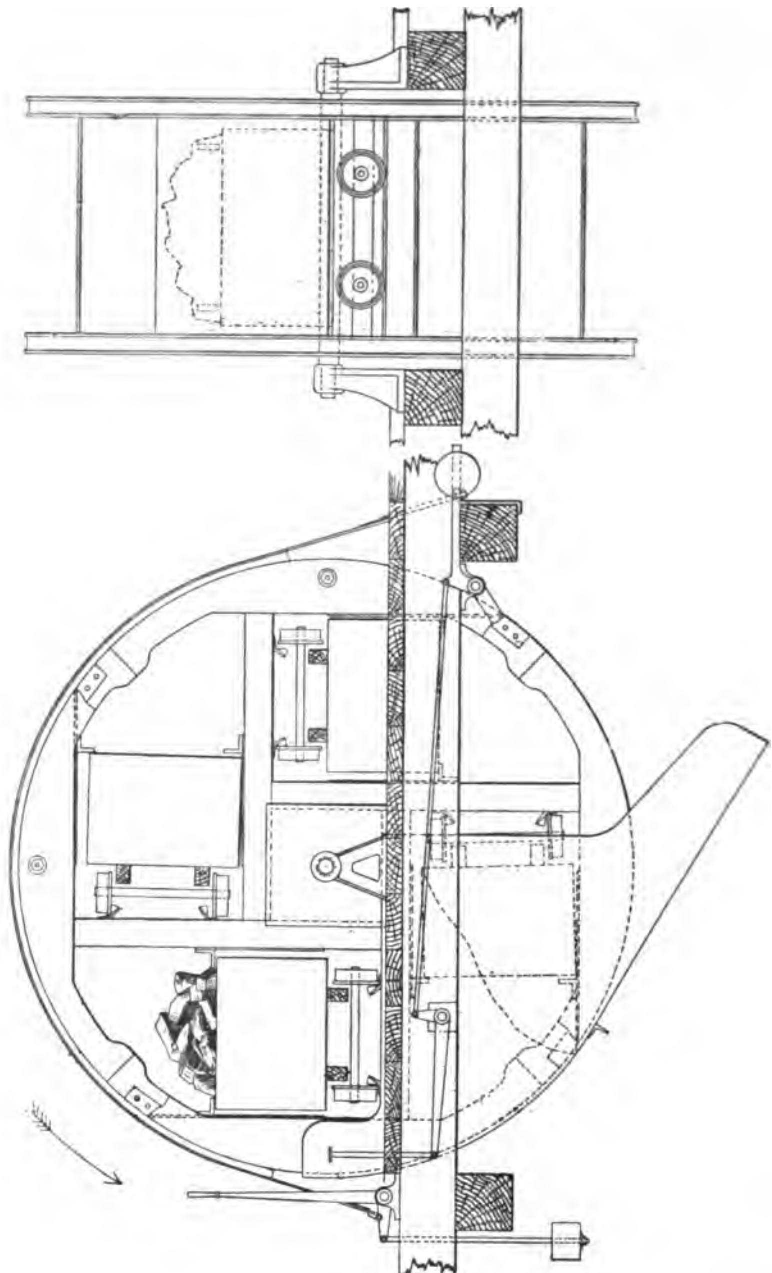


FIG. 594.—WOOD'S PATENT FOUR-BOX GRAVITY TIPPLER.

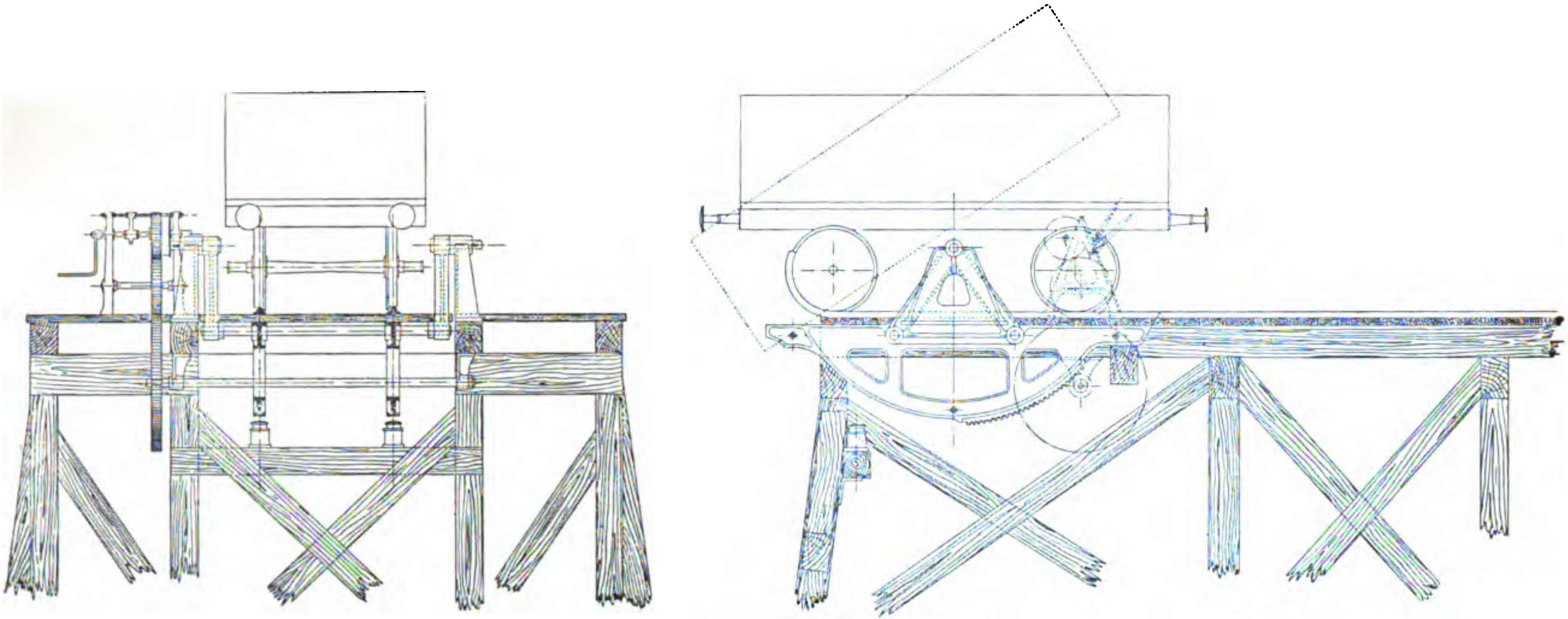


Fig. 385.—Wagon Tip.

Fig. 385 (*see page* 625) shows a tippling arrangement, worked by hand gearing, for railway wagons.

SHAKING SCREENS AND PICKING BELTS.

The coal which has been discharged from the box by a mechanical tippler finds itself still under mechanical control. The screens are mechanical in the best sense—namely, that they are shaking arrangements, producing at the end of each oscillation a shock. The effectiveness of the hand riddle over any fixed screen was in consequence of the peculiar jerking action of a hand riddle, and in so far that it is successful the mechanical shaking screen imitates the hand riddle. The amount of coal that a fair-sized mechanical shaking screen can handle is such that no fixed screen could even approach, and whilst the one dealt with a small amount ineffectively, the other could deal with four times the amount effectively. Still we have not exhausted the resources of modern pit-bank arrangements; the picking belts are an excellent part of the system, they answer a variety of purposes; the coal may consist of pieces large and small, the former of which it may be desirable to separate by hand as it passes along the picking belt, travelling at about forty feet per minute, and the separation is effected by workers along the sides of the belt; or the coal, as it comes from the pit, may contain inferior material, which can be picked and removed. When the coal has been dealt with by the mechanical shaking screen it can be transmitted by a travelling belt to any other points ready for other operations. As if all this was not enough, some of our modern collieries have elaborate washing arrangements, by means of which the coal is not only made thoroughly clean, but is divided and subdivided, so as to produce quite a variety of sizes for market.

In the old fixed screening arrangements, to induce the coal to pass down by gravitation, the inclination had to be very considerable (not flatter than one in three for large, and steeper for small coal), and the result was, that with the moderate height of pit bank then in use, the length of any one screen was limited. With the very effective shaking mechanical screen no great inclination is required, and if need be, even in moderate heights, we can obtain easily enough a substantial length of, say, twenty feet.

The general principle of these mechanical shaking screens is not difficult to understand, and a very usual arrangement is to suspend the screen itself by rods, and to provide the oscillation of any required length or speed by means of eccentrics or cranks. A fair speed of oscillation may reach one hundred double strokes per minute—that is, one hundred revolutions per minute of the eccentric shaft, giving a short, quick throw of four or five inches. Some difficulty has been experienced from the action of these mechanical shaking screens—that is to say, they exercise an uneasy influence on the staging. On one occasion the writer had to defend colliery owners against a charge of intolerable nuisance, arising from the action of these appliances —namely, the vibration and the noise. But the judge was a just one, possessed of common-sense, which is often as useful as being learned in the law, and he ruled that what would be an improper condition of things in the neighbourhood of Windsor Castle was not necessarily an unbearable nuisance in an industrial centre, where the appliances formed part of a works which found employment for the population. An arrangement of mechanical shakers for dealing with a large output does certainly produce a tendency to disturb the arrangements with which it is associated, and it is not only that a large amount of noise is produced which nobody desires, but excessive vibration will play havoc with the appliances themselves. In the old days, when pit banks had to make provision for screening arrangements, the supports, and, indeed, practically the whole of the pit bank was of timber. But timber, even of the best, is liable to get worse for wear, and timber supports to a pit bank, exposed to heavy work which may go on for half a century, cease to commend themselves. Iron pillars and iron girders established themselves, and, in the writer's opinion, the structural work of a pit bank should be as much of iron or steel as practicable. Some authorities argue that metallic combinations are too rigid, and produce the very evils that we wish to avoid. They say that timber presents a yielding and cushioning influence, which breaks the shock of the action of mechanical shaking screens. The writer does not agree, although there is no infallibility in his opinion. He thinks that the modern pit bank should be a firmly built-up structure, unyielding in its foundations, and practically unyielding throughout. To encourage any give-and-

take for this machinery will inevitably produce injurious action; keeping the whole pit bank structure, to which the mechanical appliances are attached, firm and unswerving will reduce to a minimum any unpleasantness in action.

Travelling belts have been made of quite a variety of substances, such as hemp ropes, cotton bands, chains, wire netting, but probably the best and the most generally used are those made up of plates of steel, each six to twelve inches broad and not more than a quarter of an inch thick, supported on link chains specially formed, and moving over drums polygonal in shape. These belts travel in frames, which are lined with steel plates where there is exposure to the friction of the coal, and also, with a view of making the movement as easy as may be, the belts move upon small rollers. They can be made any length—ten feet or a hundred feet—and they can be fixed in any direction to suit particular requirements. The fact is that these travelling belts enable us to have our screens arranged as may be wished, and they will bring the coal to the screens. The speed of a belt can, of course, be determined according as it has much or little to convey, and according as much or little has to be done upon it; the speed may be twenty feet or forty feet per minute. The width will depend on circumstances, because sometimes conveyance represents the whole operation, whereas at other times a good deal of picking and cleaning has to be performed. The ordinary width may be three or four feet; and really, with a good arrangement of shaking screens and travelling belts, we may avoid breakage of the fuel, we can remove all but the very fine impurities, and we can do a substantial amount of separation. The amount of mechanical power required, even for an elaborate arrangement, is remarkably small, because there is really not much actual work in the sense of raising weight. Apart from the movement of the shaking screens, what we have to do is to overcome the frictional resistance of the appliances, and more often than not the travelling belt has a descent in the direction that the coal is being conveyed. The writer would be surprised if a small pair of steam engines twelve or fourteen inches diameter did not prove sufficient to drive all the shaking screens and the travelling belts associated with one modern winding shaft with a possible output considerably over one thousand tons per day.

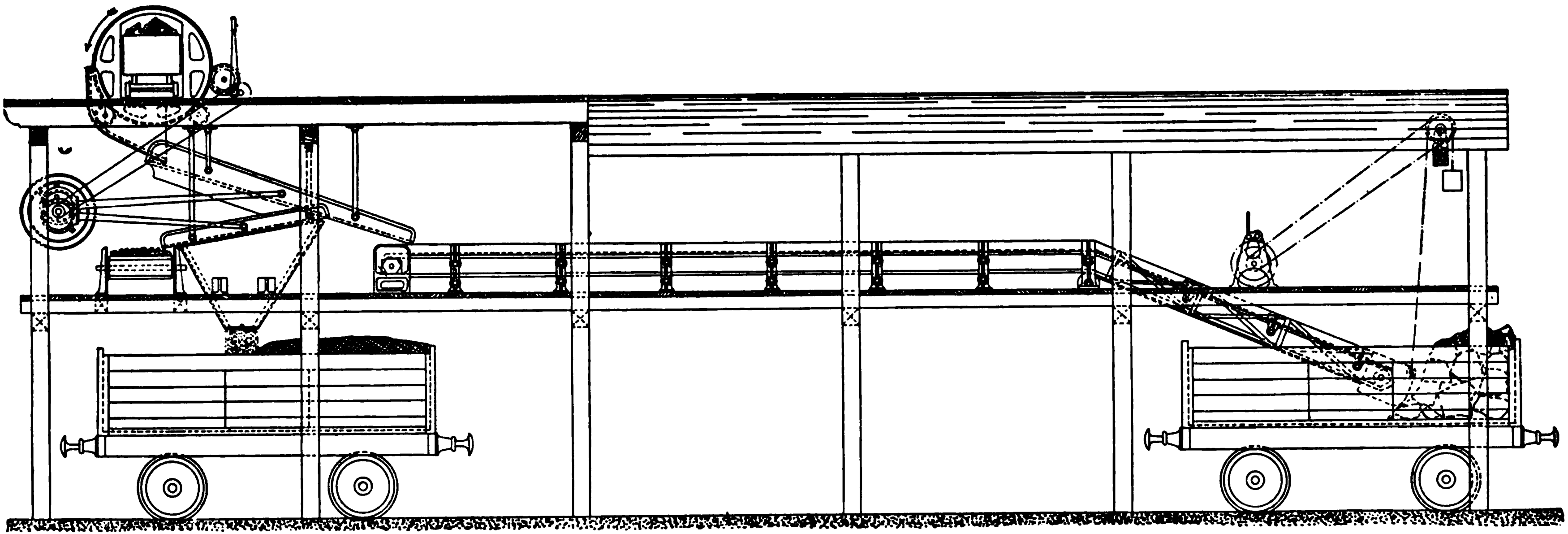


Fig. 386.

Section showing Power-Driven Tippler, Shaking Screens, Picking Belts, and Patent Lowering Jib for Loading Large Coal into the Wagons without Breakage.
Capacity 500 to 600 tons per day, making three sizes.

A number of the following illustrations have been placed at our disposal by Messrs. John Wood & Sons Limited, engineers and ironfounders, of Wigan, whose experience with regard to the production and application of colliery machinery, especially in the branches with which we are now dealing, is very extensive. Some engineers have a more varied range of work than others, and we do not enter into the question as to whether it is better to have a limited range or a wider range. In colliery engineering some firms chiefly produce winding and hauling appliances; others take up the branch of pumping machinery; others again deal with air compressing appliances; and still others have their chief occupation in ventilating machinery. There are colliery engineering firms who make headgears and pit banks, and all the mechanism for handling the coal at bank; and even those who are varied in their work make more or less of a speciality in some one section. Mechanical screening and its attendant machinery has only really come upon us of late years, and although, no doubt, most colliery engineers will, by force of circumstances, include this class of machinery within their sphere of influence, the firms of repute engaged in it are not numerous whilst the century is young. The writer went out to a modern colliery quite recently which had received the benefit of the best surface plant arrangement, and so excellent was the action that manual labour seemed quite out of place on the pit bank. Fig. 386 (*see page* 629) is a sectional elevation, which shows an arrangement right away from the tipping of the coal out of the boxes to the discharge into the wagons; it gives us the mechanical shaker, the nut shute, the shaking nut screen, and the slack bunker, with separate wagons in position to receive coal and nuts and slack. We are also shown the suspenders and the driving shaft and eccentrics. The same illustration also shows travelling belts; usually and preferably the shutes deliver the coal and the nuts not direct into wagons but on to these travelling belts, by means of which the coal and the nuts can be conveyed to any parts required. Fig. 387 shows an elevation, and fig. 388 (*see page* 632) shows a plan of a travelling coal-picking belt made of steel, so arranged as to move with the smallest amount of resistance, and the length and width of which are adaptable to local requirements.

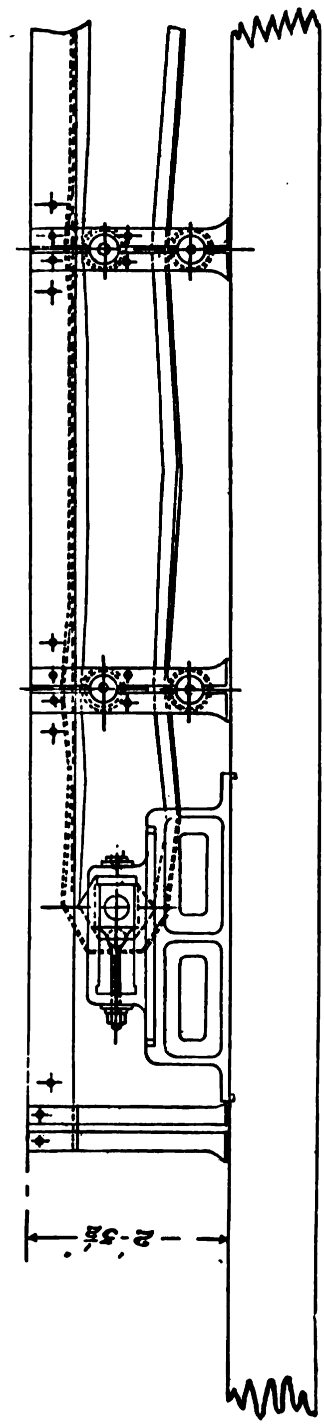


FIG. 387.

ELEVATION OF END OF PICKING BELT, SHOWING ARRANGEMENT OF TUMBLERS AT THE TENSION END.

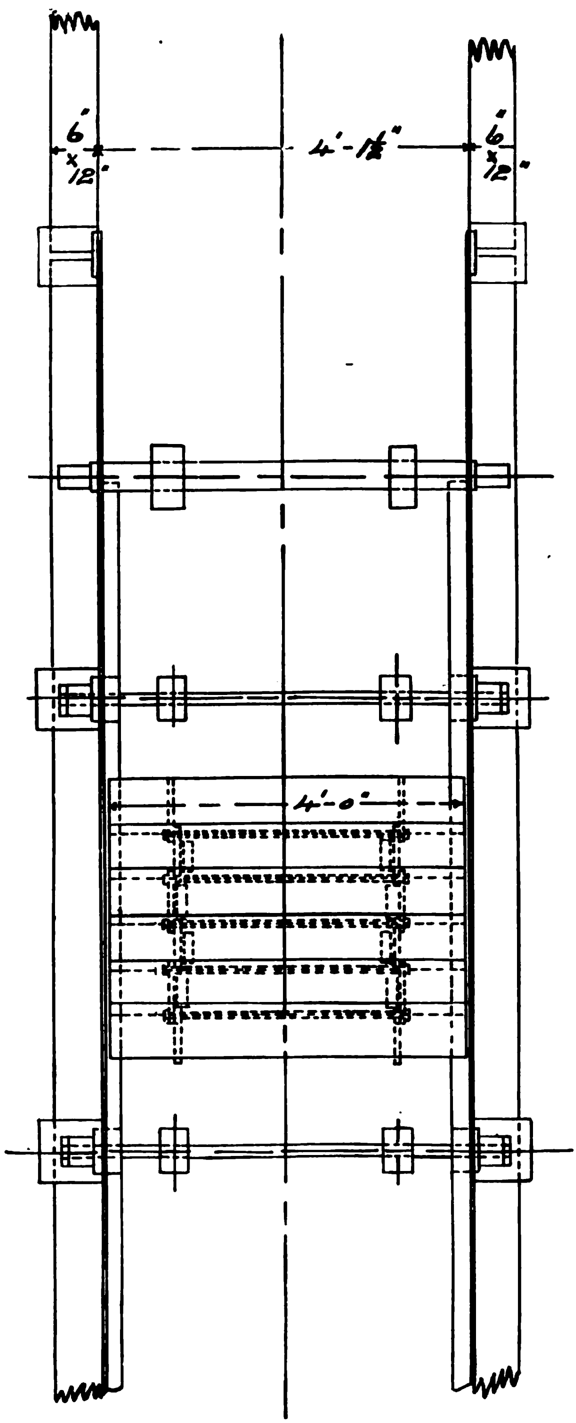


Fig. 388.

Plan of Picking Belt, showing the Steel Plates and Rollers.

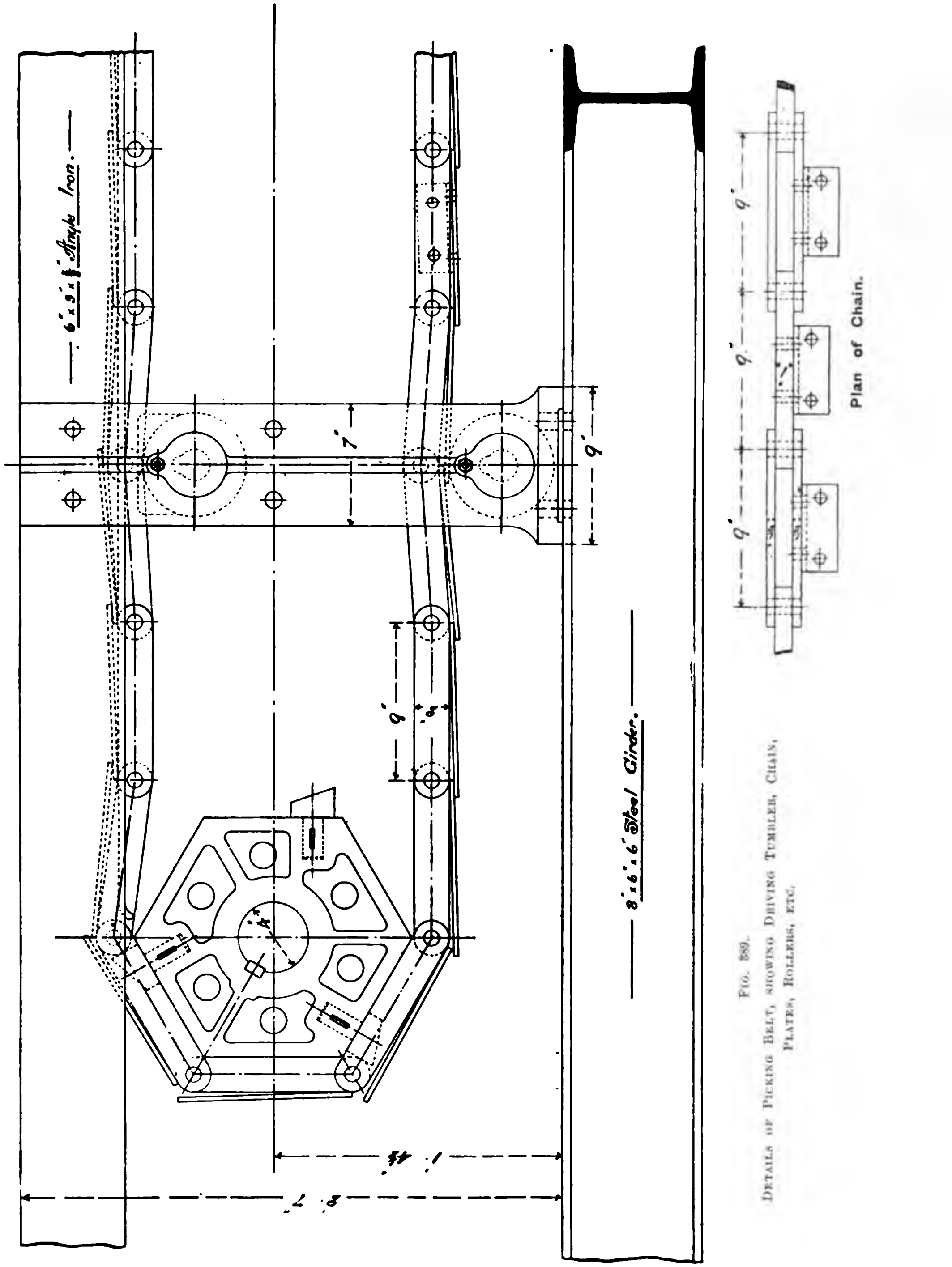


FIG. 389.

DETAILS OF PICKING BELT, SHOWING DRIVING TUMBLER, CHAIN, PLATES, ROLLERS, ETC.

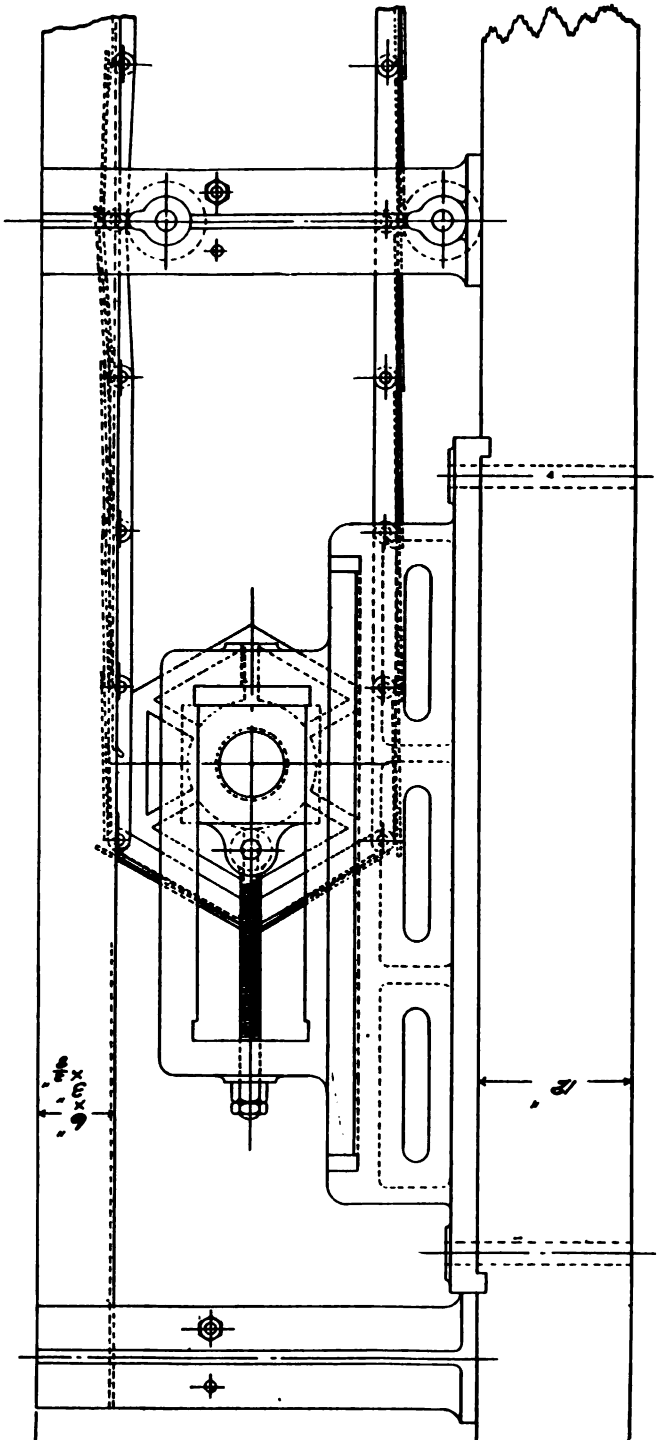


Fig. 390.
Details of Picking Belt, showing Tumbler at Tension End.

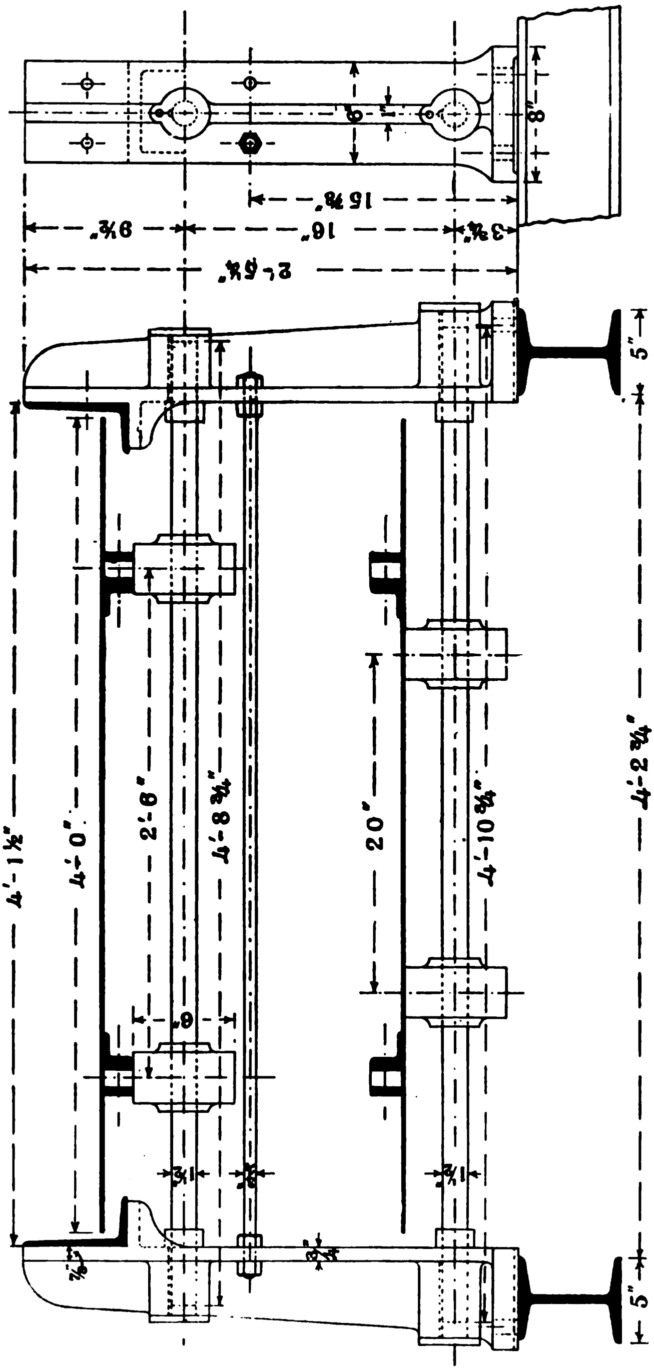


FIG. 391.
CROSS SECTION OF A PICKING BELT, SHOWING THE ROLLERS, ETC.

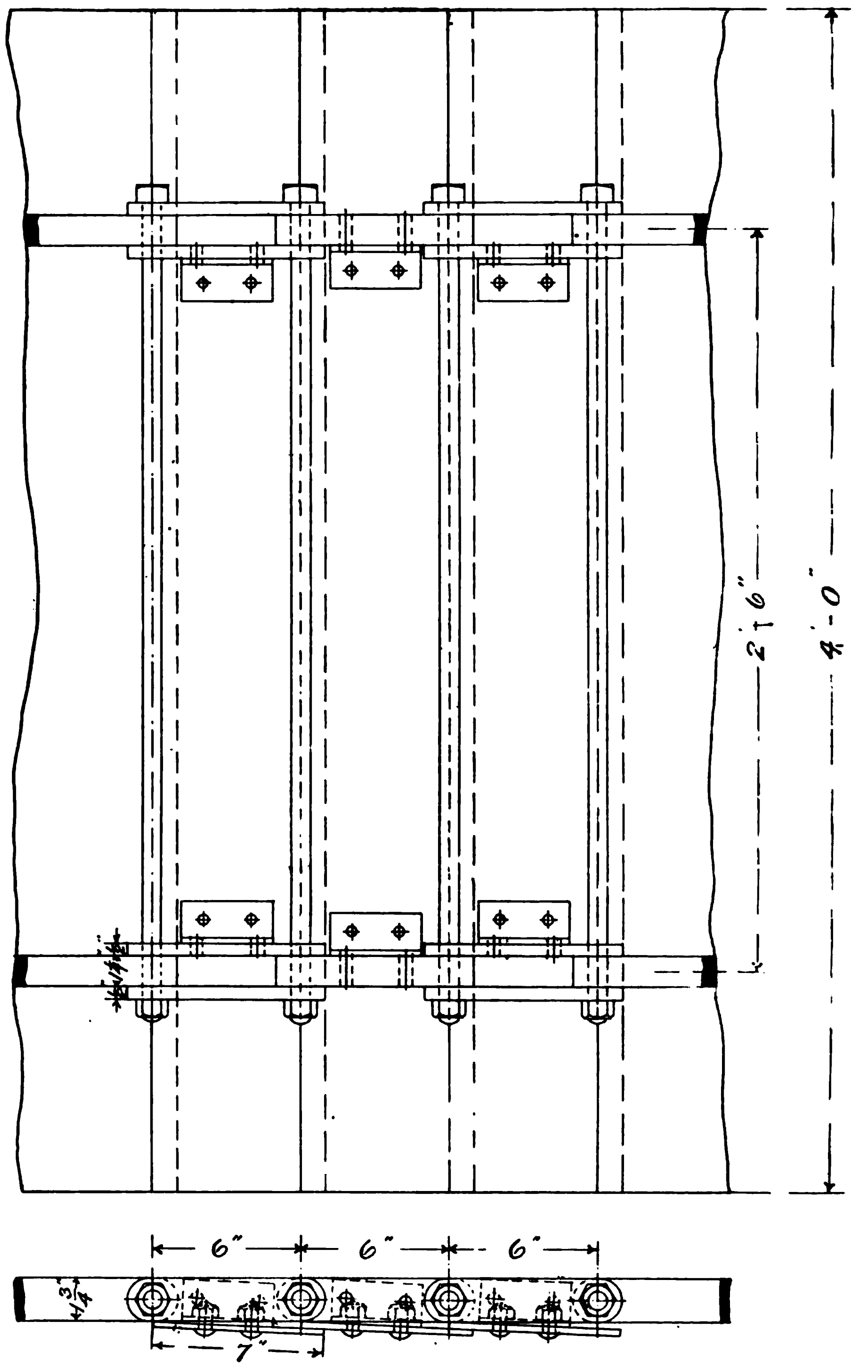


Fig. 599.—Plan of Underside of Plates, showing the Chain Links.

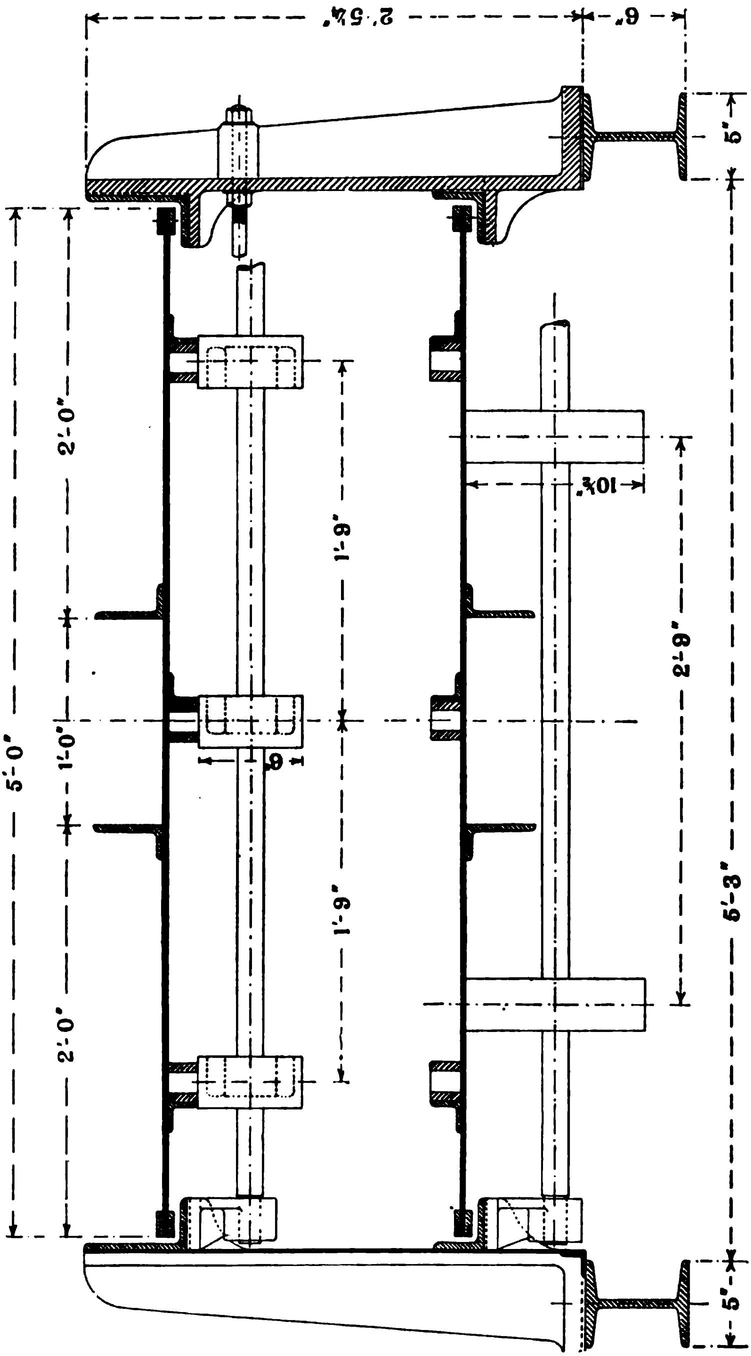


FIG. 393.—CROSS SECTION OF PICKING BELT.

The division in the middle is to receive the dirt picked out of the coal on either side, and to convey the dirt to a suitable shute or receptacle.

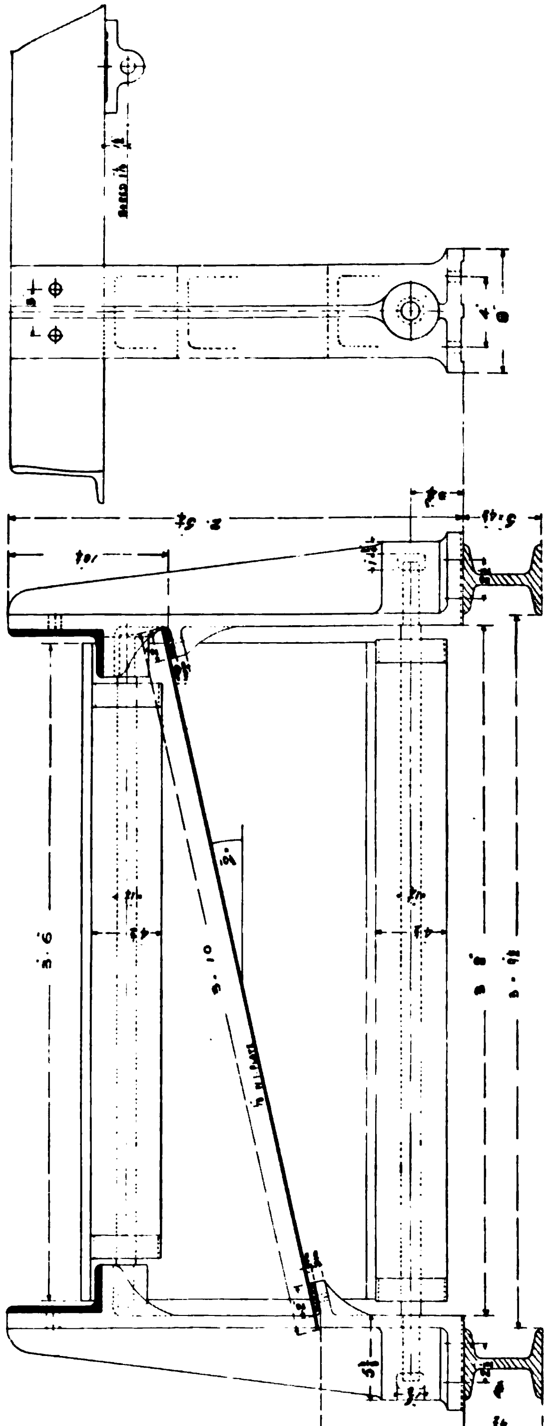


Fig. 394.

Cross Section of an Open-Mesh (Coarse Wire Gauze) Picking Belt, through which the Small Coal falls on to the Inclined Shutes.

Figs. 389 and 390 (*see pages* 633 *and* 634) give enlarged views of the hexagonal tumblers which drive the belt, also the tumblers at the tension end, and represent with sufficient clearness the arrangement of the steel plates and of the links which move upon the rollers; figs. 391, 392, and 393 (*see pages* 635, 636, *and* 637), and fig. 394 still further illustrate details of these travelling belts as in actual and successful use.

The travelling belts may, and frequently do, lie in the same line as the screens, but they may, if need be, and frequently are, placed at right angles to the screens; that is a matter of local necessity, but in the latter case the mouth of the shaking screen is cut at an angle so as to distribute the coal evenly on the belt. It is considered good practice to couple the driving shaft direct to the eccentric shaft, and the action of the fly-wheel has been found very useful when placed on the eccentric shaft, as it carries the eccentrics over their dead centres very effectively, and greatly reduces the tendency of vibration in the whole system. We mentioned a little further back that travelling picking belts could be of any length in reason; there are some striking proofs of this to be found in the Midland coalfield, where a good deal of hand picking has to be done to lift out the large coal, which, of course, will fetch a much higher price. What we want in such a case is to place the coal from the pit on to a travelling belt as readily as possible, and alongside that we can have a second and a third travelling belt. We remove from the one to the other, and each goes on its way to its particular place of loading. In one arrangement there are two steel travelling belts, the one measures two hundred feet from centre to centre of tumblers, and receives a hundred tons of coal an hour. All the large coal is removed from this belt, whilst the small coal which remains is carried forward to a second belt measuring one hundred feet from centre to centre of tumblers. The large coal would appear to be deposited on each side of the first belt, and presumably carried forward into its wagons by mechanical means. The small coal requires the operation of screening, and for this purpose has a rising gradient, so as to deposit the contents at a sufficiently high level upon a mechanical shaking screen, where the needful further separation is effected. A somewhat similar arrangement is illustrated on sheet 14 (*pages* 526 *and* 527).

Fig. 395 (*see sheet* 20, *between pages* 640 *and* 641) shows, in plan and elevation, a complete tipping, screening, picking, and conveying plant for an output of from six hundred to seven hundred tons per day.

All the coal is tipped by means of one tippler, of the mechanically-driven type, with automatic stop motion.

The tippler shute is fitted with a curved back, in order to minimise the breakage in delivering coal on to screens.

The screens are of the double type—that is, two shakers worked in opposite directions by eccentrics from a four-inch steel shaft. The shakers divide the coal into three sizes—namely, coal, nuts, and small.

The coal passes over screens, and is delivered on to a steel-plate picking belt, four feet wide, and fitted at the ends with a Wood and Burnett patent lowering jib, of the continuous type. The coal is thus discharged into wagons with practically no fall, and the jib is gradually raised as the wagon fills up.

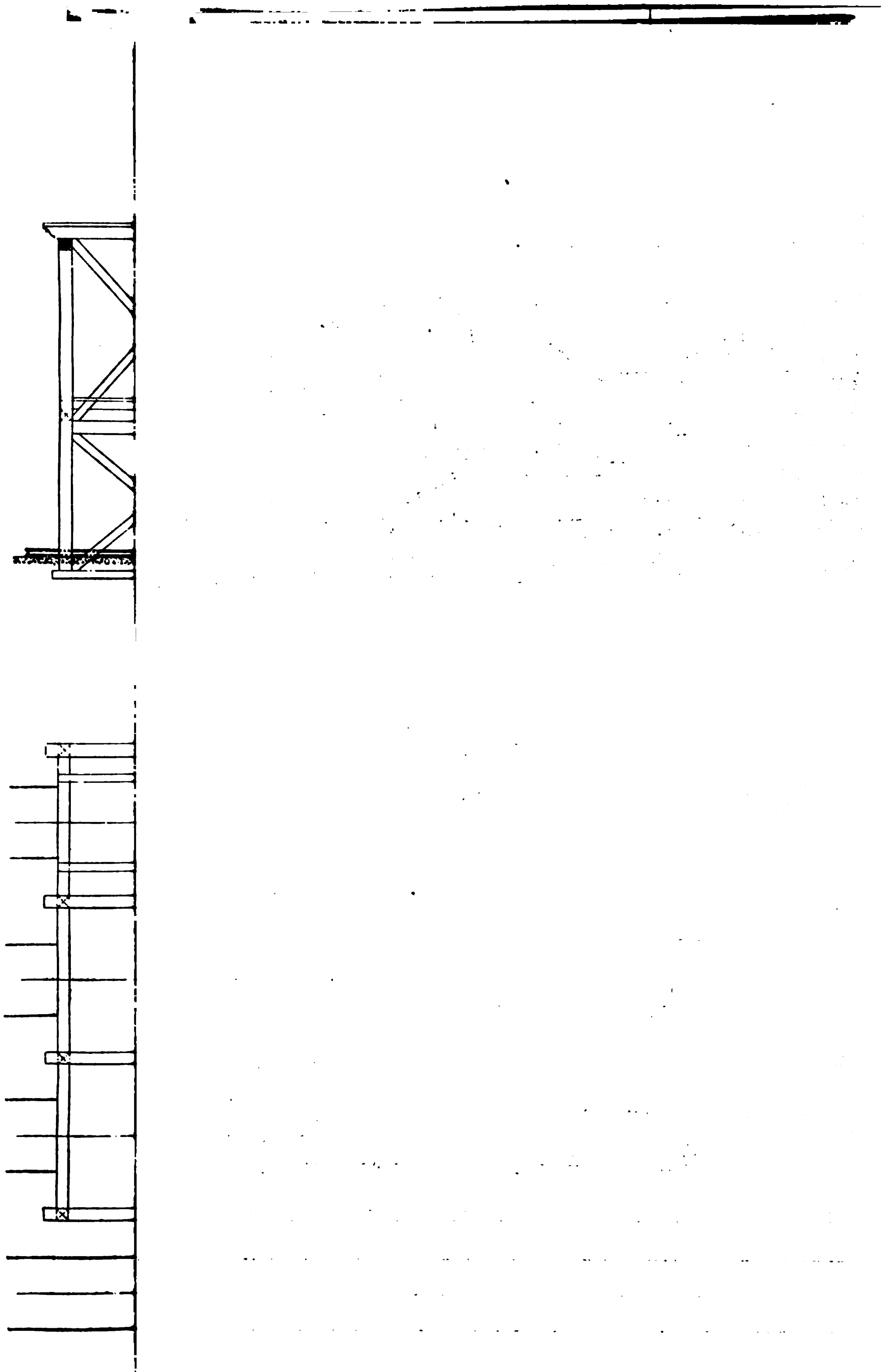
The nuts, from the under side of the second screen, are delivered on to a cross-shaking tray, which in turn delivers them on to a steel-plate picking belt, fitted with lowering jib, exactly similar to the one for the round coal.

The small, which passes through the first screen, is collected and delivered into a scraper conveyor at right angles to the screen. This conveyor discharges the small either into a hopper directly over the wagons on the slack road, or, by opening a slide in the trough, into the boot of an elevator.

The elevator then lifts the small, and discharges it into a revolving screen, fitted with two circular wire screens for making two sizes of nuts, and dant or duff.

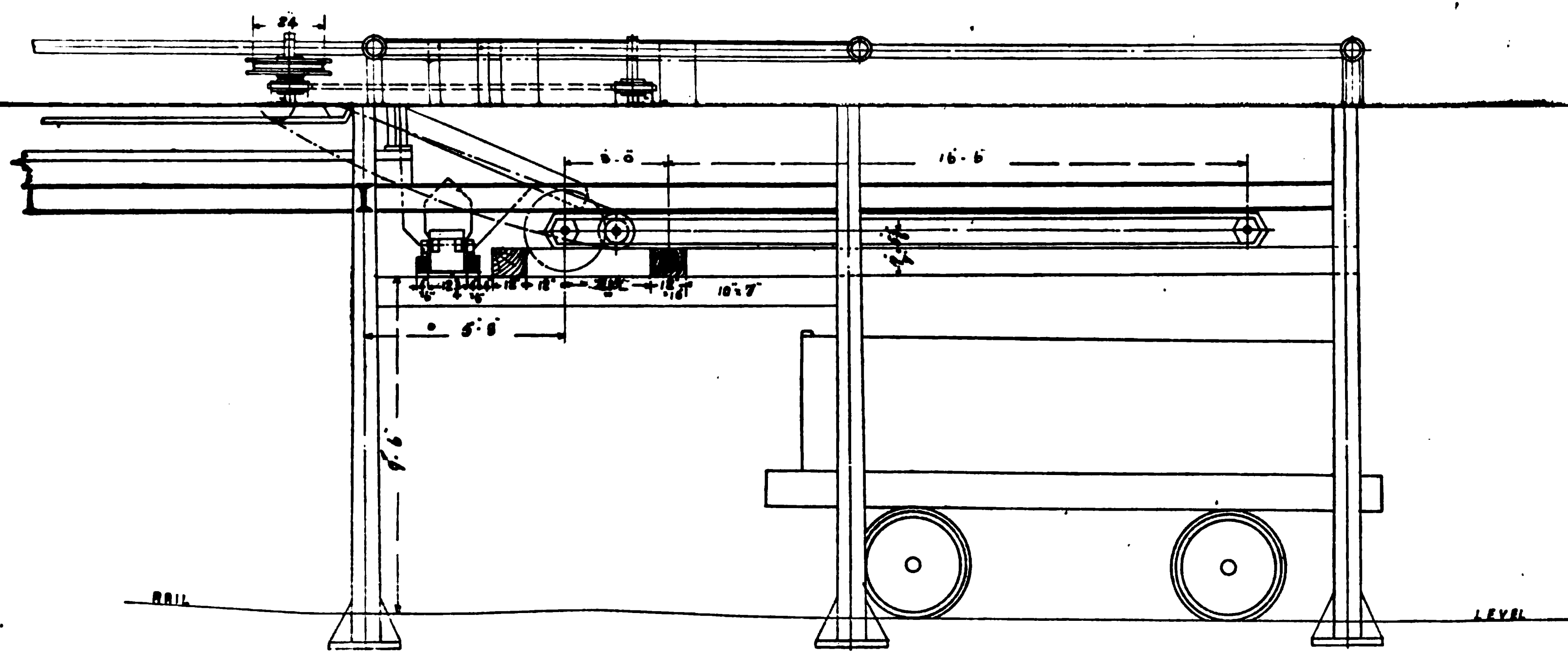
The larger of the two sizes of nuts is conveyed down a long shute on to a steel-plate picking belt, for hand picking. This belt is fitted with a hinged apron for delivering into wagons. The smaller nuts are delivered direct into hopper over wagons; the dant or duff is also delivered into a hopper over the outside road. The whole of this plant is driven by a pair of horizontal steam engines, of the twin type, fixed on one bedplate.

The machinery for making small nuts—including elevator, revolving screen, and nuts picking belt—can be put into operation by one clutch, and each picking belt is also fitted with a friction clutch, so that any belt can be stopped when wagons are being changed.



PLAN AND

SHEET 21.



ELEVATION.

FIGS. 398 AND 399.—SHOWING DETAILS OF LOWERING JIB.

Fig. 396 (*see page* 642) is an elevation of an arrangement of four-box tippler and screens, for making six sizes, working at a colliery in Leicestershire, constructed for dealing with one thousand tons of coal per day.

In this arrangement it will be seen that in the first screens everything but the large coal passes through on to the second screen. This operation is repeated on the second, third, and fourth screens—that is, in every case the large only is passed on, and the rest falls through the screen.

The coal is delivered on to a picking belt, and from this the large pieces are lifted off by hand and placed on a sloping plate, which runs the entire length of the belt. Men standing in the wagons take the coal from this plate, and stack it in the wagons.

The cobbles also are delivered on to a picking belt, and both this and the large coal belt are fitted with patent lowering jibs. The large nuts are delivered on to a cross picking belt, fitted with shute at the end for delivering into wagons. The small nuts and slack are delivered direct into wagons.

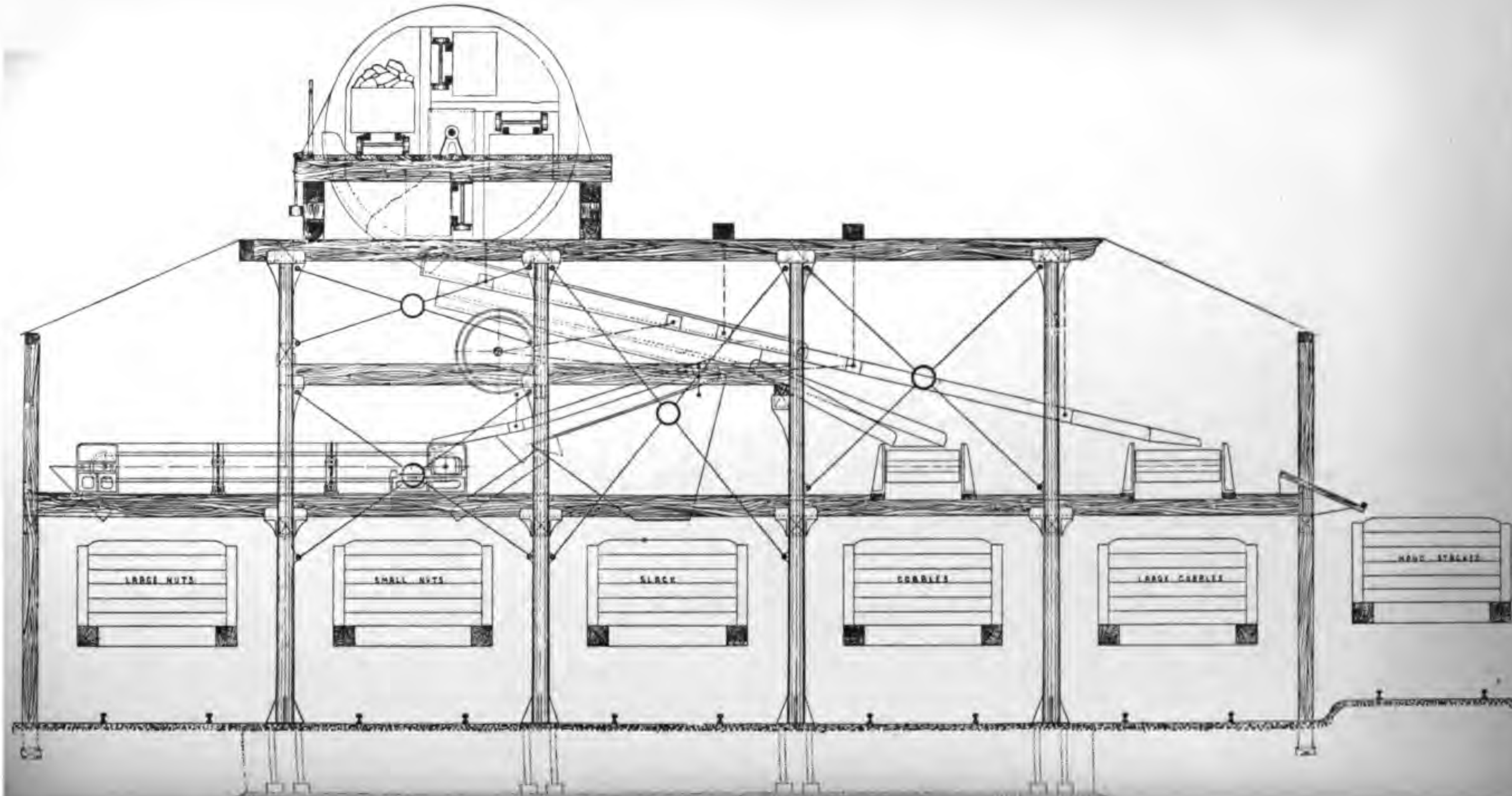
Fig. 397 (*see page* 643) is the elevation of an arrangement of screens for making five sizes.

After the hand-picked coal has been removed on a long conveyor, the remainder is delivered by the same on to the top end of the screens. These are of the double type, working in opposite directions, and fitted with three sets of plates. The first is for small only, which passes through into a hopper underneath, directly over wagons; the second mesh is for pea nuts; and the third for large nuts, which, in both cases, are delivered on to picking belts. The cobbles, which pass over screens, are also delivered on to a picking belt.

Figs. 398 and 399 (*see sheet* 21, *between pages* 640 *and* 641) show details of the lowering jib, which has been referred to in several of the plants described, for the purpose of lowering the coal and cobbles, without breakage, into the wagons.

RAILWAY WAGON CONTROLLER.

Fig. 400 (*see page* 644) is an illustration of a useful contrivance for manipulating the railway wagons under the screens whilst being loaded. Its object is to facilitate and regulate the movement of the wagon, and enable the coal to be properly



LARGE NUTS
SMALL NUTS
SLACK
COBBLES
LARGE COBBLES

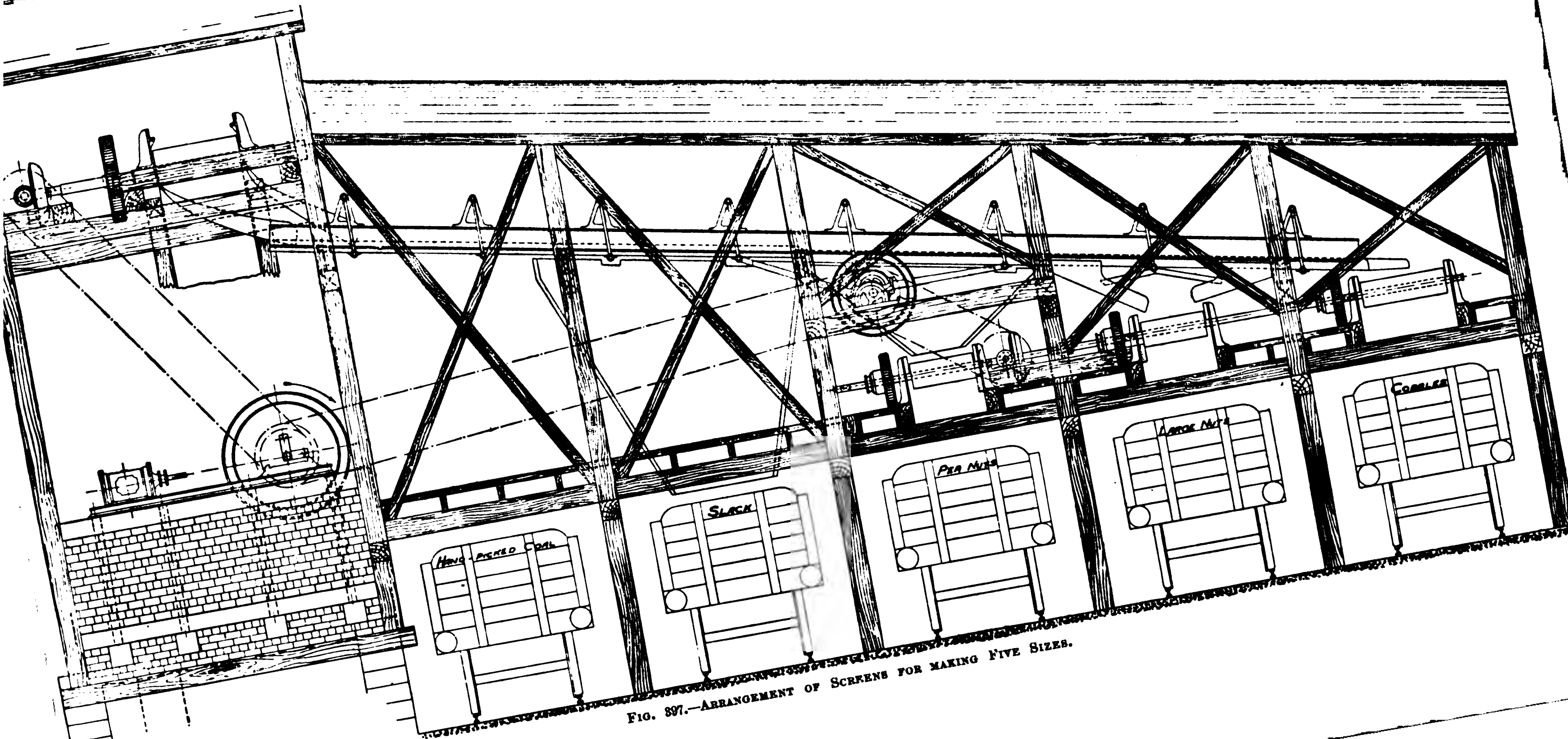


FIG. 897.—ARRANGEMENT OF SCREENS FOR MAKING FIVE SIZES.

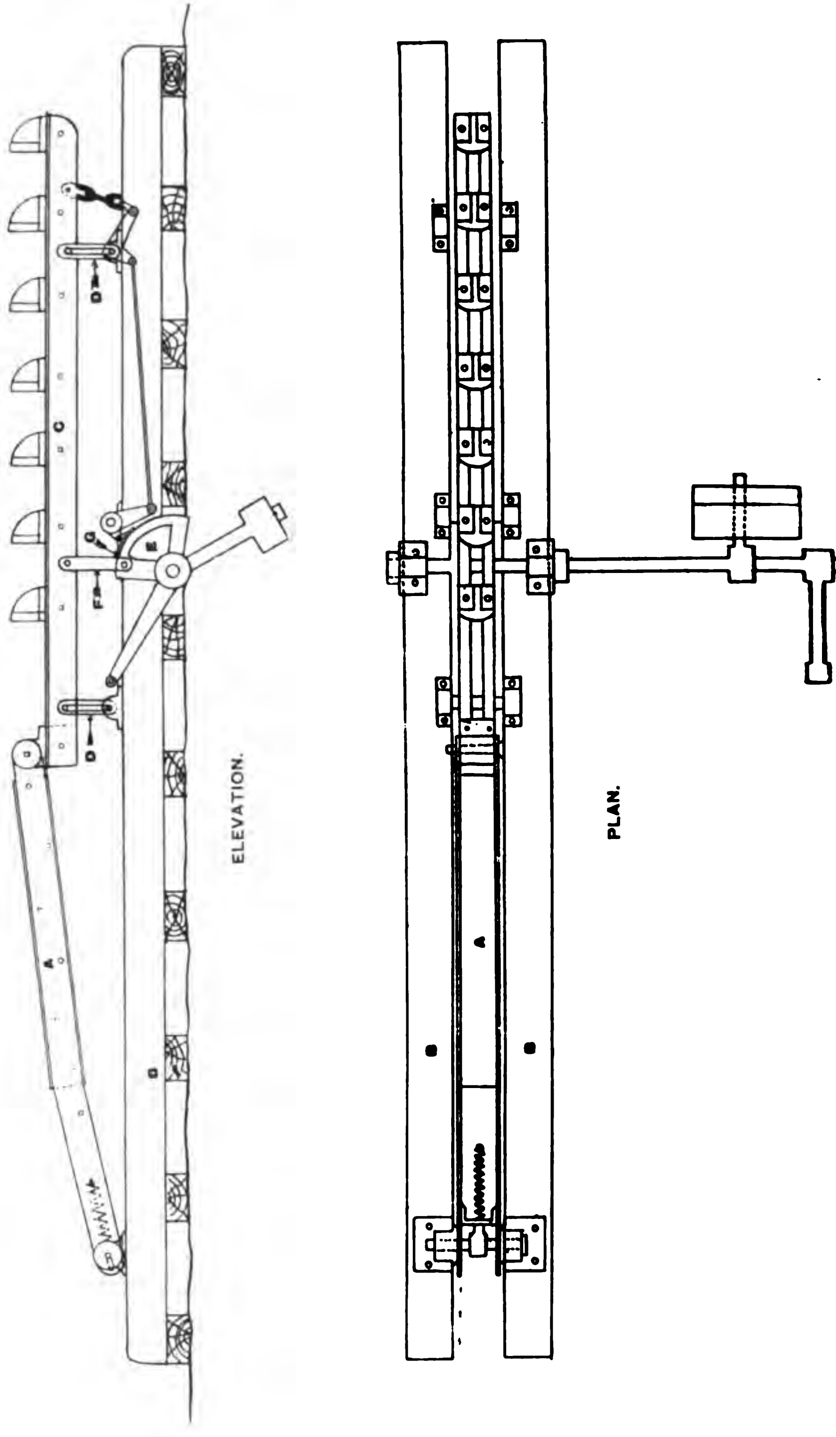


Fig. 400.—Miller & Yates' Patent Railway Wagon Controller. (The wagon moves from left to right.)

trimmed. It saves labour and the cost of labour, and removes one source of accident.

The whole apparatus is controlled, and the shifting of the wagons effected, by the wagon trimmer from the level of the scaffold on which he stands, without requiring him to come down to the rail level.

It is designed to be operated by hand lever, or by hydraulic or other power appliances, from any point within convenient reach of the trimmer in charge of the loading operations.

It operates upon the axle of the wagon, and in no way interferes with the rails or railway.

It is very simple, easily fixed and put to work, the whole thing being put down in the centre of the railway under the screen or table, and fixed to the railway sleepers.

The apparatus consists of a wooden lever-bar **A** strapped with iron plates, placed longitudinally between the rails and above their level, and pivoted to a crossbar carried on brackets, fixed to two long wooden beams **B**, secured to the sleepers at a point where an incline is formed to facilitate the movement of the wagons.

To the upper or free end of the brake lever **A** is hinged or pivoted another iron lever-bar **C**, having projecting upwardly from it a number of equidistant paws or catches. A powerful spring is also attached at the pivoted end of the brake lever **A** to cushion the shock given to the lever by the axle of the moving wagon coming in contact with the catches.

This catch-bar lever, which is guided by slotted links **D** pivoted to it and to the two longitudinal beams **B** below, is raised or lowered vertically by means of a quadrant **E** and link **F** by a hand lever or other convenient means within reach and under control of the trimmer. In working the apparatus, the wagons are allowed to run slowly down the incline (which at most collieries is about one in seventy-five) until the front axle of the wagon reaches the previously-raised lever-bar **A**, which slows and stops the wagons.

The trimmer, then, by means of a hand lever, lowers the brake lever, and frees the axle of the wagon, so that immediately the axle of the wagon slips over, and clear of the brake lever, it is caught and held by the paws and catches on the front lever.

The loading operation is then commenced, and as it proceeds, the catch bar is lowered at suitable intervals by the trimmer, to allow the wagon to move forward, step by step, the distance between the catches, so that in loading from a screen or shute, the wagon may be properly trimmed, and by the regular and systematic shifting of the wagon, breakage of the coal is considerably reduced.

The brake lever, acting upon the rear axle of the wagon, prevents sudden movement, and insures that the wagon will only shift from one catch to the next in succession.

The catches are suitably spaced to ensure the proper trimming of the wagon.

Instead of the brake lever and catch lever requiring to be raised to engage with the wagon axle, they are normally maintained in the raised position by a counter-weight, and lowered by a lever, under control of the trimmer, to disengage the axle, and permit of the wagon moving forward from catch to catch.

The apparatus is provided with an automatic safety brake G acting upon the quadrant E, and obtaining its power from the catch lever itself.

This brake appliance, in the ordinary course of handling empty wagons, is not required, but is provided as a safeguard in event of, say, the wagons coming down upon the brake lever at considerable speed, or any excessive weight being put upon the brake lever. Under such circumstances, the axle of the first wagon would engage with, and travel upwards along, the brake lever, until the front wheels of the wagon got lifted off the rails.

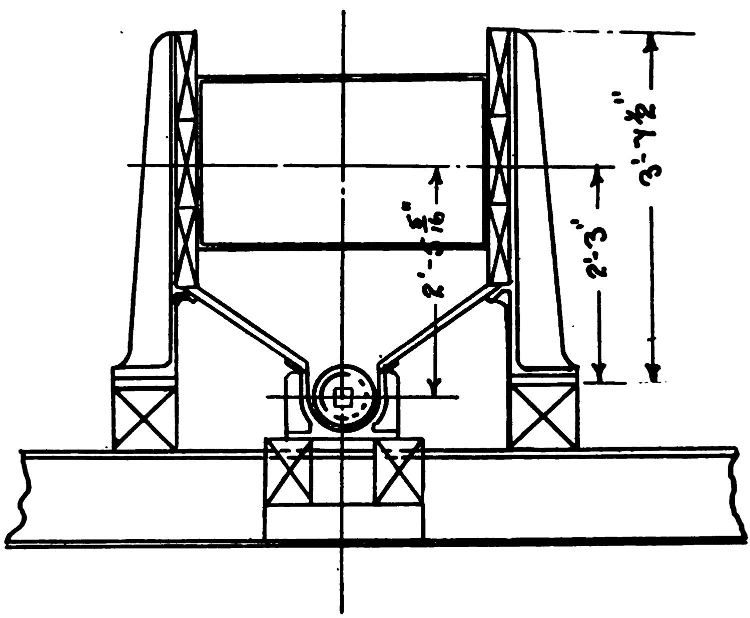
That being so, the brake lever would have an excessive weight thrown upon it, and when the trimmer moved his hand lever to disengage the axle, the apparatus might be lowered suddenly with a shock. The brake prevents this, and the more weight that is applied upon the brake lever the higher the catch lever is inclined to rise, and, consequently, the more powerful does the brake become.

This apparatus has now been working at a modern colliery, under daily supervision, for some considerable time, and has given the greatest satisfaction in every respect, both as regards its practical usefulness, economy, and simplicity in working, and, since the day it was started, the man who was formerly

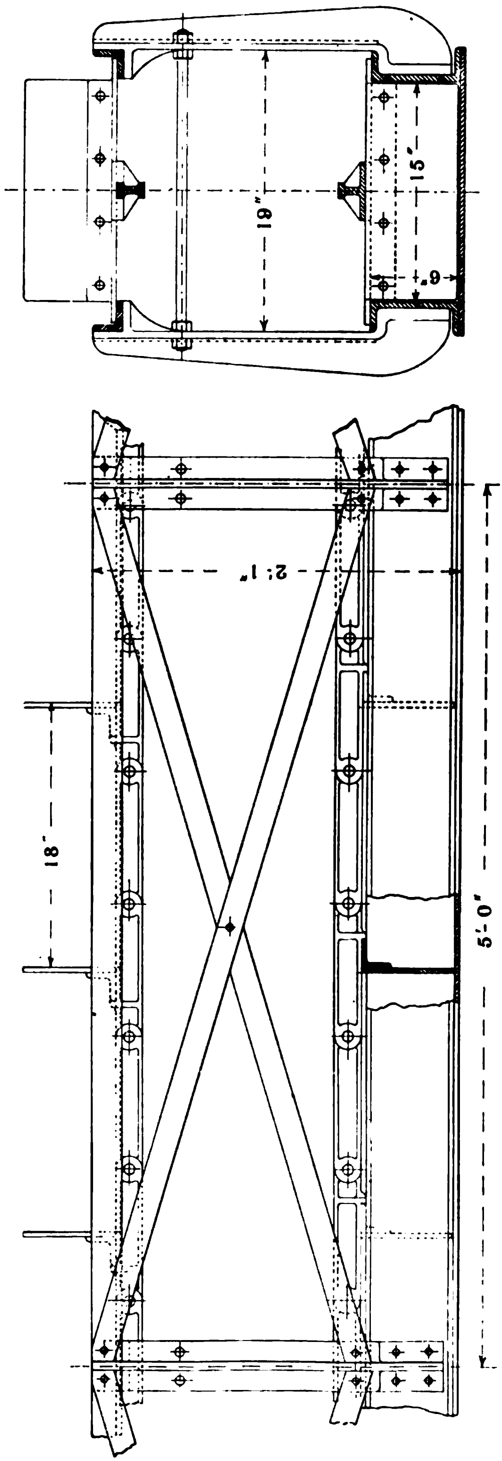
employed as wagon shifter has been dispensed with, and the wages saved during that time have more than paid for the apparatus.

In the writer's earlier investigations as to the picking and screening of coal he had quite an interesting experience. During a visit to the Burnley coalfield, chiefly connected with the method of haulage so much identified with that district—namely, the endless chain—he noticed a mechanical screen on the same principle that some of our mechanical boiler stokers have been designed and constructed. It consisted of bars which had a combined movement in the line of the screen, and also a circular movement in a vertical plane, which caused the bars to rise and fall. Alternate bars moved upward and forward simultaneously, carrying the fuel with them, whilst the others moved back in succession, thus liberating themselves from the coal, and avoiding the bringing back, which would have spoiled the operation. This mechanical screen did good work, and although it worked slowly, it passed very much more coal over than an ordinary fixed screen, and separated the sizes much better. But it was not the thing; no steady movement to and fro could separate the various sizes of coal; it requires the shaking influence which is the salvation of the mechanical shaking screen. The special interest of the incident had to follow the visit to Burnley. The writer went on the continent with the members of the Institution of Mechanical Engineers, and visited some of the more important of the Belgian collieries. A special feature, to which the attention of the English visitors was drawn, was an endless-chain method of haulage which was marvellously like the Burnley method; and another item which delighted the Belgian hosts was a mechanical screen which was to all intents and purposes similar to the Burnley screen. The writer was struck with the similarity, and asked how this had come about. The Belgian engineers said that the ideas were theirs, and no doubt we English had copied them. But, said the writer, these arrangements are new, and in the Burnley coalfields they have been in operation for a generation; how could English engineers copy what did not exist? On his return home the writer made another visit to the Burnley district, and on enquiry found that a party of Belgian engineers had been there

a few years previously, and had obtained full information both with regard to the endless-chain system of haulage and the mechanical method of screening. Honesty, no doubt, is the best policy, but the slimness of the Boer is not confined to that particular race.

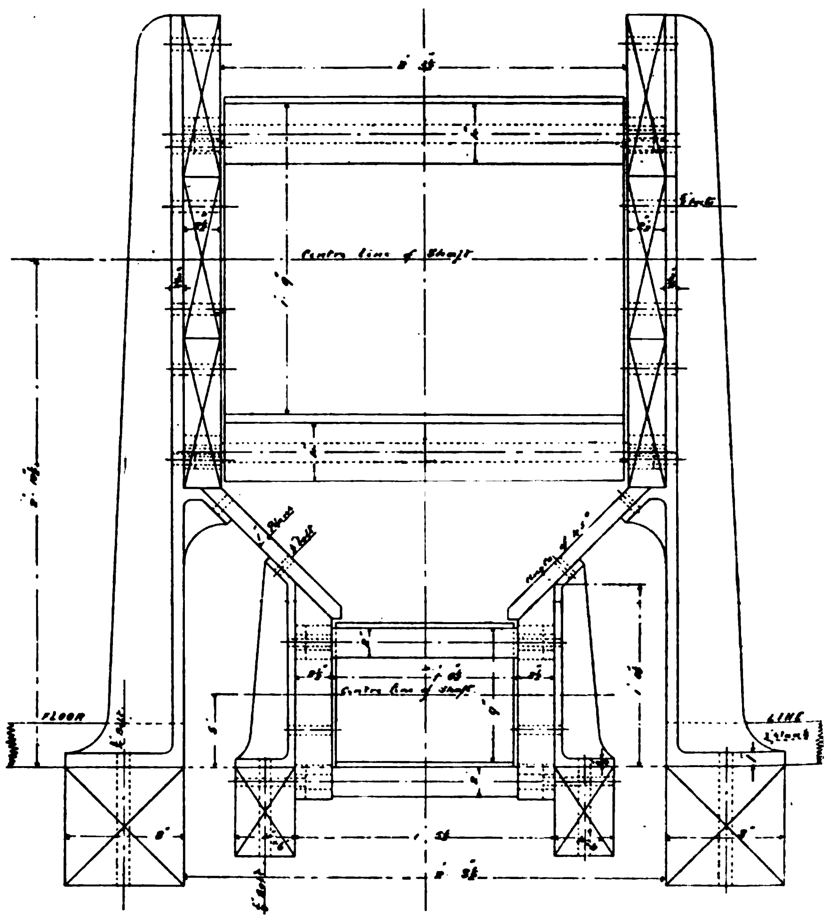


Cross Section of Picking Belt, in which the Belt is Coarse Wire Gauze, through which the Small Coal falls to be dealt with by the Worm Conveyor at the Bottom.



SECTION AND ELEVATION OF A SCRAPER CONVEYOR.

The scrapers are secured to the endless chains, and scrape the coal, from right to left, along the bottom trough.



Cross Section of an Open-Mesh (Wire Gauze) Picking Belt.

The small coal falls through on to a conveying belt which runs the whole length of the picking belt.

CHAPTER XIV.

THE WASHING AND COKING OF COAL.

IN dealing with the subject of coal washing and washing machinery, we may fairly, without trespassing beyond the range of colliery mechanical equipment, bring in the purpose for which coal washing was first applied, and for which it must always be chiefly applied—namely, to prepare coal for its manufacture into coke.

In concluding this chapter we shall attempt to give a brief description of at least one important modern method of coke manufacture, which seems destined to play an important part in our industrial welfare, and probably not much will be necessary with regard to the ancient method of coke manufacture, which, let us be as stubborn as we may, is destined to pass out of existence. The march of industry compels us—let us hope willingly, so far as our readers are concerned—to adopt the modern method, which is more efficient and economical, and abandon the ancient, because of its cost. In cleaning coal by what we may call the dry method—namely, picking—we can only remove comparatively large lumps of inferiority, and where there is no fine coal to be manipulated that is sufficient. But most mining districts, now that we try to bring as much out of the mine as possible, have a very large amount of fine coal, and the coal, fine or otherwise, contains a considerable amount of dirt far too fine to remove by any dry method. What we want for the market is clean coal, and if the coal can be cleaned its smallness is not necessarily an objection, since in the manufacture of coke we actually adopt means to make it fine to get better coke. For coke manufacture alone, in the United Kingdom, considerably over 20,000,000 tons of coal a year are used, and the proportion will not be less in

other great coal-producing countries, such as the United States of America. The writer will not in this matter speak for countries except his own, but in the old country, at any rate, coal washing for coke making is held in deserved importance. Even apart from coke manufacture the thorough cleaning of fine coal, only possible by washing, is of great value. Down to a certain size the cleaning by washing will improve the value in the market for general purposes; and even the dust of the coal, if clean, will find a useful application in the making of briquettes, in which fine coal, in combination with material sufficiently cohesive, is made into the form of bricks, and is used for domestic and other purposes. The writer cannot say from his own knowledge that coal briquette making is a large industry, or has developed much of late years, but he does know that such productions can be conveyed to any distance without loss, and he does not know why it should not constitute an increasing item in the coal industry. There are certain well-developed methods of coal washing which have been attended by more or less success, and it will be sufficient for our purpose to touch upon these methods; there is no method quite perfect, and all have advantages. It may be remarked as fortunate that the large proportion of the impurities requiring to be removed consists of materials of greater specific gravity than the coal with which they are intermixed, and the chief aim of our appliances is to enable the influence of gravitation to operate.

The simplest method of coal washing is that known as the trough system, and although there are those who say even yet, that given a sufficiency of water supply and a sufficiency of length and height, there need be no better method, it has become practically obsolete. The coal, after the operation of screening and hand picking, leaves the slack intended for washing in hoppers. From these a travelling belt conveys the slack to the foot of an elevator, and by means of the chain of buckets the slack is elevated to any required height, and deposited into a revolving riddle, which separates the slack into nuts and finer material. These nuts, although not intended for coke making, experience the benefits of washing; having passed through the riddle they enter a higher trough (the finer material separated from the nuts has passed into a lower

trough), and there is the advantage of ample height and ample length, also a sufficient head of water. The inclination of the troughs is about two inches vertical to a yard horizontal. At the point where the actual and vigorous washing takes place, the inclination is somewhat reduced—namely, to one and a half inches to the yard. The nuts are manipulated in a double trough, so that one trough may be always at work, and the finer material is operated upon in two double troughs. The finer portion of the coal chiefly contains the impurities, and the troughs used are about a hundred feet in length, as against little more than half the extent for the nuts. The washing troughs are divided crosswise by doors into several chambers, and the attendants thoroughly stir up the coal in each chamber. Then when one trough appears to be fairly well filled with dirt, and to be free from coal, which has flowed on with the water, the current is diverted into the alternate trough, and the dampers being removed the dirt is expelled. The nuts, having undergone their cleansing, are passed into wagons for sale, the water goes back to be used over again, and, as will be easily understood, is in a sufficiently good condition, because there has been no separation, worth speaking of, of very fine dirt from the nuts. The finer material, after the enjoyment of its washing, is conveyed over another range of troughs, and passing over an inclined sieve has a considerable amount of moisture removed by the action of an endless scraper band. From this point this finer coal is conveyed on to an upwardly-inclined travelling band, which is also a sieve, and which still further drains off the water. This travelling band delivers the fine coal into the crushers, fashioned after the form of an ordinary mortar mill, the aim being to reduce the whole of this fine coal to a uniform size, which will pass through a perforated bottom in the crusher and fall into a hopper. From this deposit an elevator takes it and places it in small wagons, which run along the tops of the coke ovens and charge them.

There are various methods of reducing the size of coal for coking; this is one, rollers afford another means, but probably what we call disintegration is the best. The disintegrating machines are simply discs with projecting bolts a few inches in length and arranged in circles. The discs revolve in oppo-

site directions, and the projecting bolts pass between each other. The principle is very simple and the action is very effective. The fine slack is delivered into the disintegrating machine in which the discs are moving very rapidly; opposing motions are set up in the pieces of small coal, and they are ground practically to dust by the disintegrating action of the projecting bolts or studs. Trough washing, to be efficient, requires an abundant water supply, especially when the coal is dirty; probably a hundred gallons for each ton of coal. Such a water supply is not always available, and there are countries where with abundant water there is the liability to freeze; the system entails much manual labour which lacks both economy and uniformity. Even the very abundance of water supply causes waste, because some coal is inevitably carried away with the water.

THE ELLIOTT COAL WASHER.

However the actual separation of the coal and dirt is effected all coal-washing appliances depend upon the behaviour of substances of different specific gravities in water, and to effect the separation more perfectly the water must be in motion. In some washers the water takes the form of a quickly-moving stream, as in the trough washer just referred to; in others the water is delivered into the bottom of a tank, in which it produces a continuous upward movement; whilst in others, again, a rapid vertical oscillation is imparted to the water. Each type is briefly described and illustrated in the following pages. For the moment we are concerned with the Elliott washer, which is an improvement upon the old trough washer, and one in which the operations proceed without interruption or the necessity for alternation between two troughs.

The Elliott washer is made by the Hardy Patent Pick Company Limited, of Sheffield. From the illustration, fig. 401, which shows the general arrangement, it will be seen that the coal to be washed is delivered on to the washing trough rom a hopper, at about the middle of its length. The trough, which is made of wrought iron or steel, has sloping sides about eighteen inches wide at the top, and narrower at the bottom. At either end of the trough a sprocket wheel is fixed, operating an endless chain provided with scrapers. These are

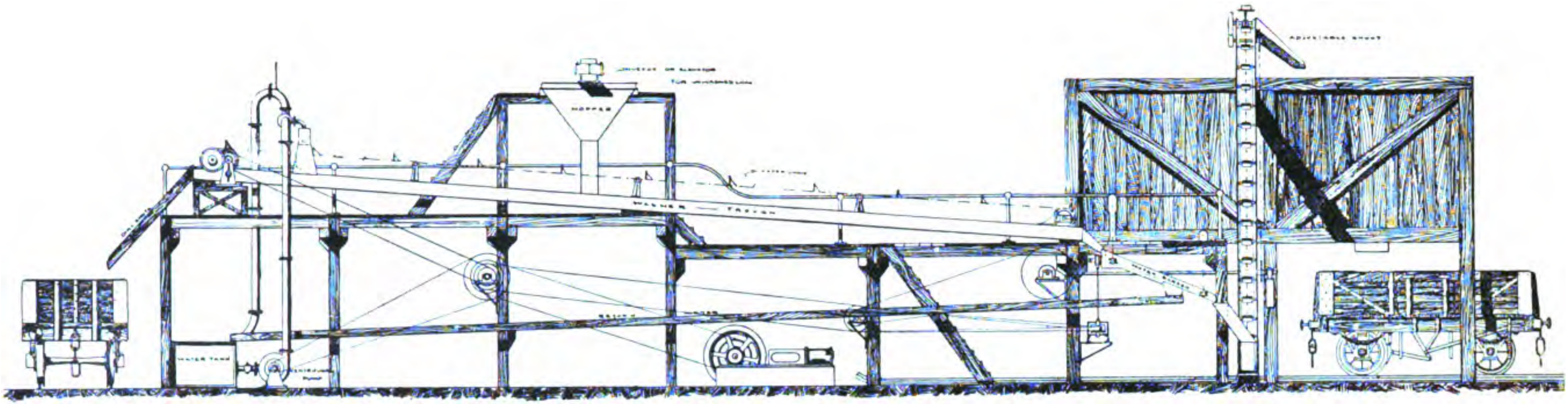


FIG. 401.—THE ELLIOTT COAL WASHER.

slowly moved along the trough, which is suitably inclined, in an upward direction, so that the scrapers meet the stream of water and continuously tend to carry the material to be washed against the stream. The water is delivered into the trough at the top end, and as it flows down carries with it the lighter coal, whilst the heavier dirt is carried forward by the scrapers and delivered, at the upper end of the trough, over a shute into the dirt wagon, or otherwise, as desired. The washed coal is delivered over a water strainer or perforated shute, thence to be dealt with by the elevator, which raises it into the loading hopper. The water returns to the water tank to be used over again.

THE ROBINSON COAL WASHER.

The Robinson Coal Washer, illustrated in fig. 402, and figs. 403, 404, 405, and 406 (*see pages* 658, 659, *and* 660) is an example of the action of a continuous upward stream of water. It cannot, perhaps, be regarded as ranking with the more elaborate modern washers, and it will suffice in these pages to give the briefest account of its operation.

The portion of the appliance in which the actual washing of the coal is effected appears in section in fig. 402. The washing vessel takes the form of an inverted cone with a series of perforations near the bottom, through which water from an elevated tank is forced. The water ascends through the cone, and overflows with the washed coal by the shute at the right. The volume and velocity of the water has to be carefully adjusted to suit the respective specific gravities of the coal and the dirt; the former being the lighter is borne upward and carried away with the overflow, whilst the latter, heavy enough to descend in spite of the upward current of water, settles in the cylindrical space at the bottom. It will be seen that this cylinder is provided with two slides, operated either by levers or by hydraulic cylinders. Whilst the washing is in progress the top slide is open and the bottom one closed; when it becomes necessary to empty the accumulated debris, the top one is closed and the bottom one opened, allowing the debris to fall into the wagon **M**. (*See fig.* 403.)

The action of the water is assisted by the revolving stirring arms, operated by a small engine, which also works the elevator.

Figs. 403, 404, 405, and 406 (*see pages* 658, 659, *and* 660) give a good idea of the general arrangement of the Robinson washer. The coal to be washed is brought to the elevator pit, from whence it is raised to the washer; here it is dealt with by the water and the stirring arms in the manner already described. The water cistern or tank is shown in the upper part of the structure, from which a pipe conveys the water to the bottom of the washer. The

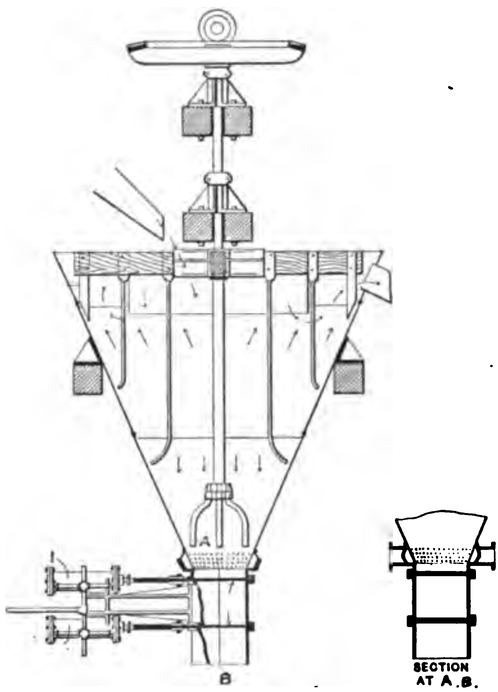


FIG. 402.
THE ROBINSON COAL WASHER; SECTION OF THE WASHING TANK.

washed coal and overflow water leaves the washer by a perforated shute, which delivers the coal into the hopper J, after allowing the water to fall through the perforations into the tank I. From this tank the water is pumped by the pulsometer back into the upper tank, to be used over and over again.

The maker does not appear to have made exaggerated claims for his appliance, and the percentage of impurity left in the coal would not be acceptable to the coke manufacturer who desired to produce coke of good quality. He claimed that the

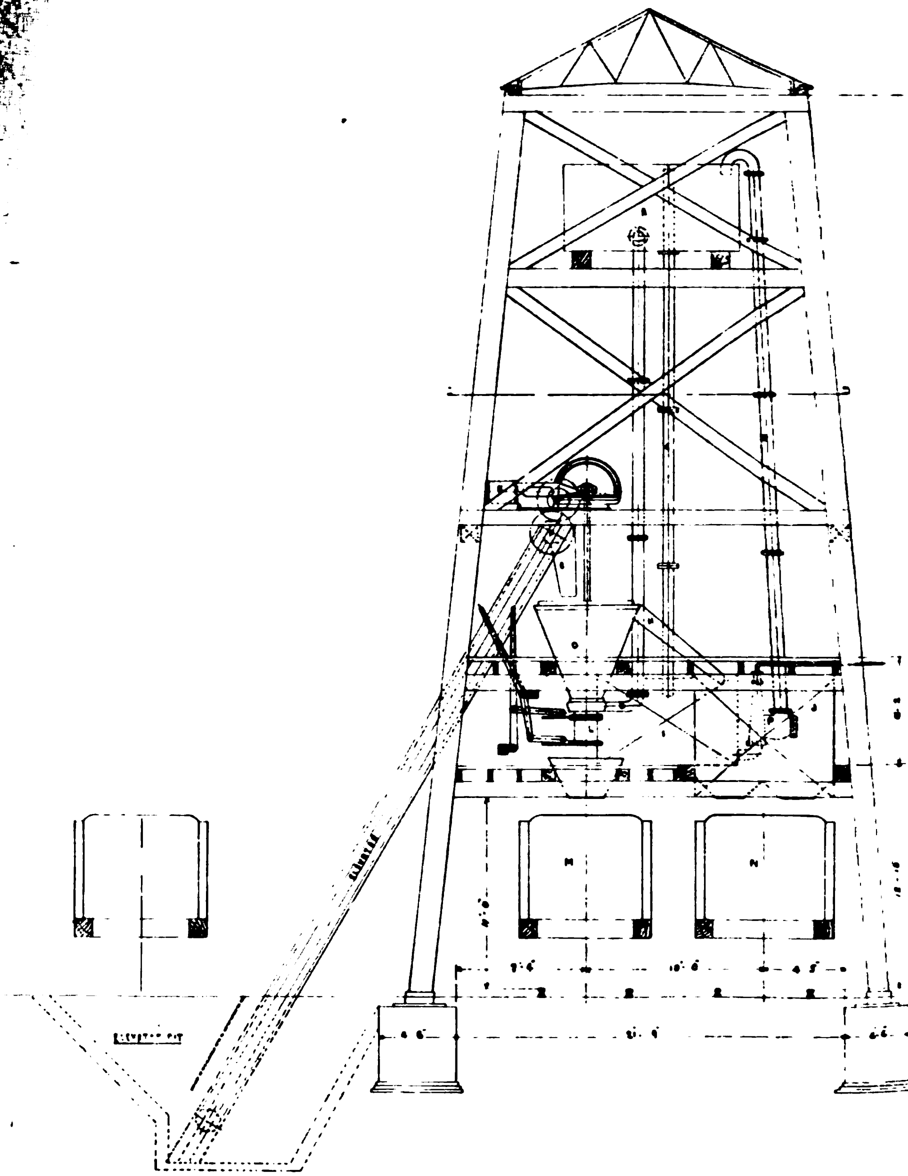


FIG. 403.

GENERAL ARRANGEMENT OF THE ROBINSON WASHER.

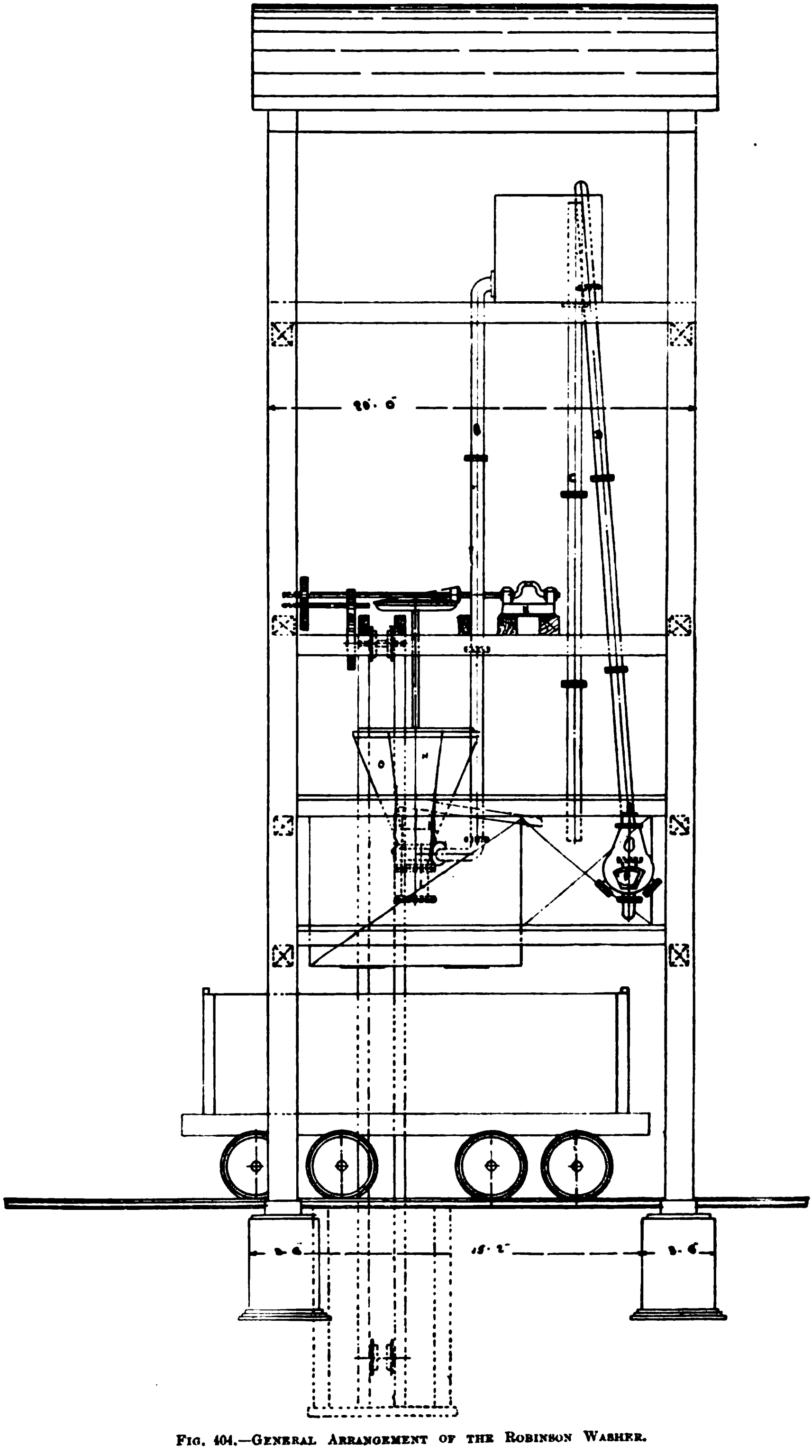


FIG. 404.—GENERAL ARRANGEMENT OF THE ROBINSON WASHER.

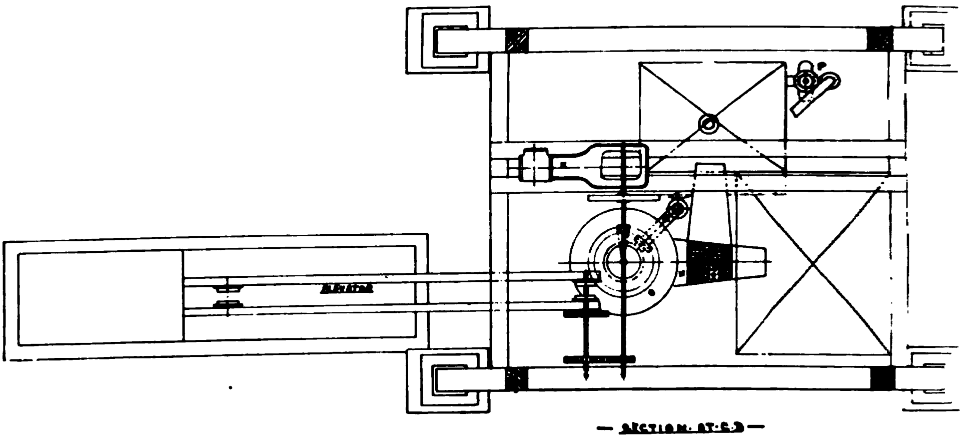


FIG. 405.
PLAN OF THE ROBINSON WASHER.

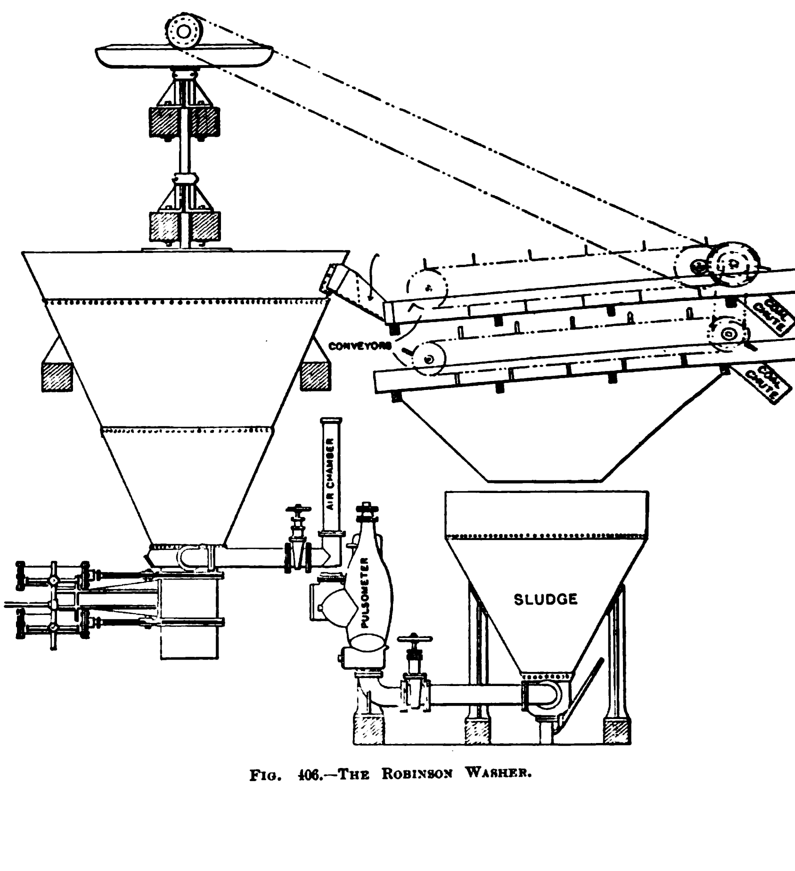


FIG. 406.—THE ROBINSON WASHER.

cost of washing was small, that the loss of coal in the operation was small, and that the construction was simple, the fixing inexpensive, and the repairs easy. He also claimed that the loss of water was not considerable. A reference has been made, in describing the Robinson washer, to the pulsometer. This has a more elaborate reference in connection with the section on pumping, and it will suffice to say here that in coal-washing arrangements, in which a very impure liquid has to be dealt with, it is a very excellent servant, for the simple reason that, although somewhat costly in its action, it will not only pump liquid which almost runs to a solid, but is not deterred in its useful career by having to deliver an occasional brickbat.

THE SHEPPARD WASHER.

The name of Sheppard has been honourably identified with coal washing in the United Kingdom, and although the place of manufacture is located in South Wales, and naturally this particular appliance found its chief adoption there, a good many installations may be found in other parts of the country. We present it here by illustrations and description, not as a type of the higher kind of coal washing, because we cannot fairly include it in that class, but because it may fairly be accepted as a very excellent arrangement of the partial endeavours to wash coal, of which we have so many examples. During the latter years of the last century there were nearly a hundred complete plants erected, and something over four million tons of coal were operated by the process. The claims are that the Sheppard machine is self-contained, and that no foul water is discharged from it; also that the fine coal is not carried off, but is retained and utilised. There are only two discharges from the machine—one for clean coal, and one for impurities; the coal is said to be so thoroughly washed as to be free from impurities, and, on the other hand, the impurities pass away without any mixture of coal. This is claiming a good deal, and it is no reflection upon the Sheppard washer to say that there is no coal-washing arrangement, even of the most elaborate character, which does all this. We of the mining community are practical men, and are reasonably satisfied with something short of ideal perfection. The danger of such claims is not so much to the user, who can mix with

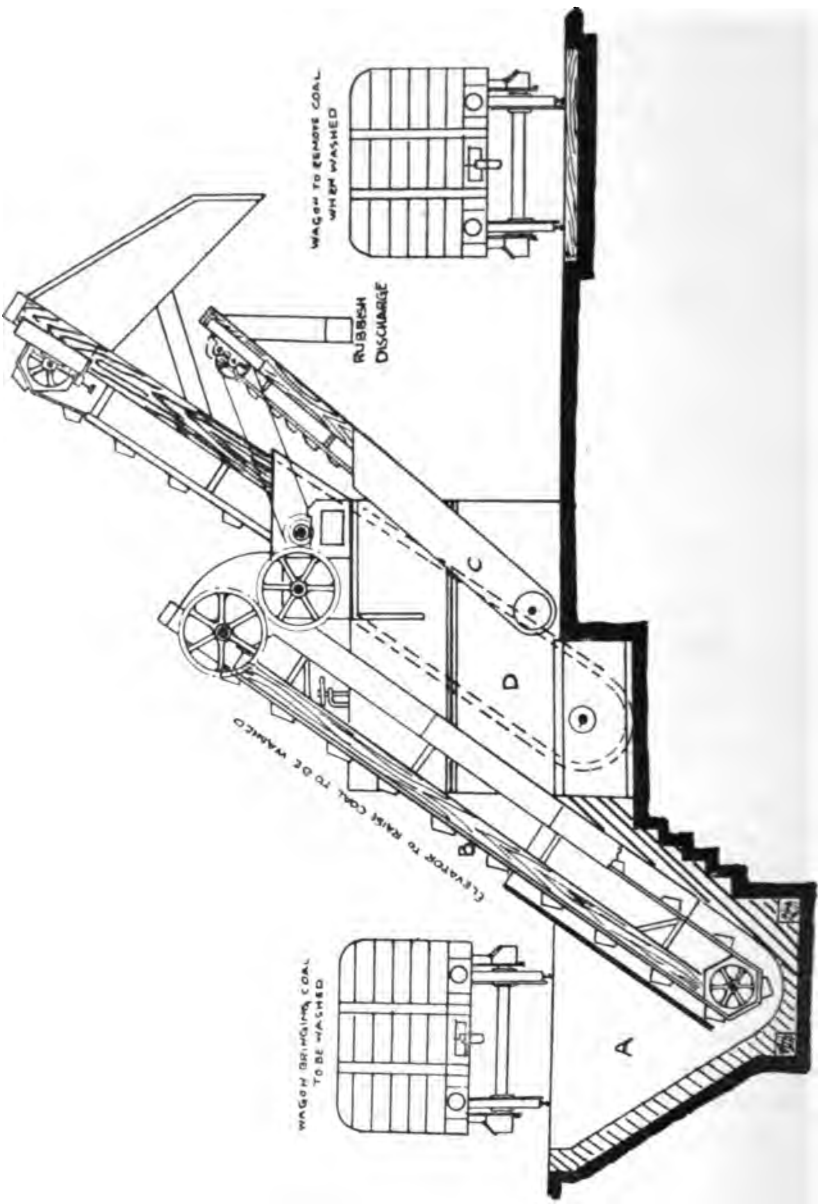


FIG. 407.—THE SHEPPARD NUT WASHER.

the overdone claims a pinch of salt; the danger is to the maker, because he is less likely to make an industry by impossible than by possible claims. In the elevation of the washed coal and the impurities separately after washing, the elevator buckets being perforated, the water drains off, and is

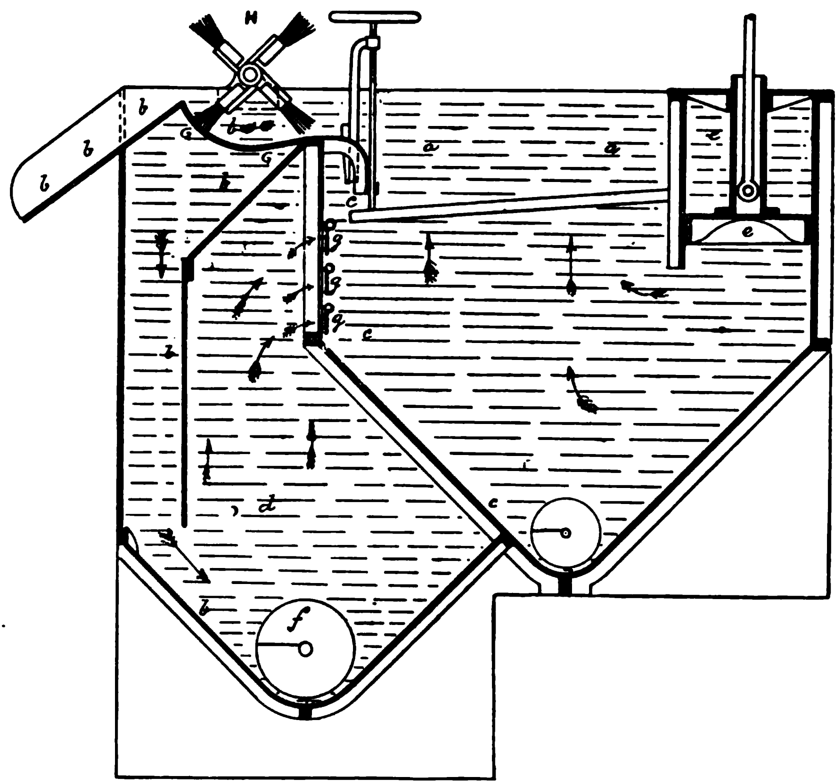
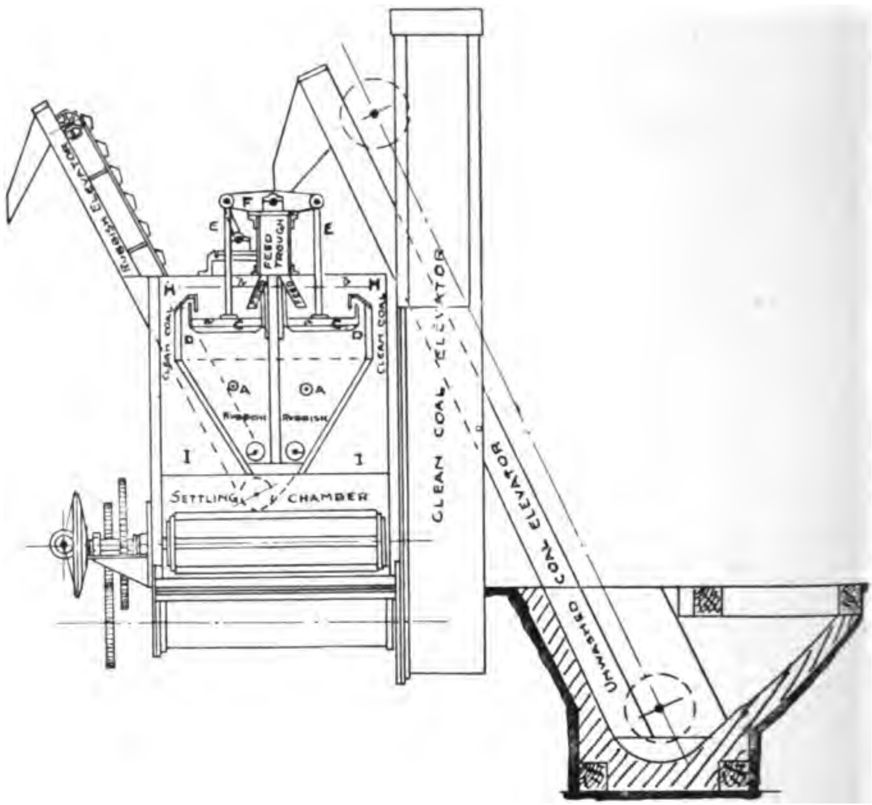


FIG. 408.
THE SHEPPARD NUT WASHER.

all returned to be used over again. The consumption of water is said to be very small, the loss being only the moisture in the coal and dirt and that due to evaporation. No pumps are needed to pump back the water from settling ponds, the settling chamber being in the machine, and an important part of it; the fine coal is elevated at the same time as the large coal, and goes to form one uniform quality of coke when used for coke making. The cost of washing is small, the labour

required being inconsiderable, and the driving power required is not great; the cost of maintenance is slight, and the machine occupies only a small amount of space.

The Sheppard coal washer is illustrated in figs. 407, 408, 409, 410, and 411 (*see pages* 662, 663, 664, 665, *and* 666 *respec-*



SECTIONAL ELEVATION.

FIG. 409.
THE SHEPPARD FINE COAL WASHER.

tively), of which the first two represent the nut washer, and the three latter the fine coal washer, for coal passing through quarter-inch mesh.

Referring to figs. 407 and 408, the unwashed coal is delivered into the hopper at **A**, and raised by the elevator *to* the washer; the washed coal is delivered by the middle elevator **D**, and the dirt is discharged by the elevator **C**.

Fig. 408 (*see page* 663) shows an enlarged section of the washing tank. The coal is delivered by the elevator into the tank at *aa*, where it enters the water, which is kept in a state of rapid vrtical oscillation by means of the plunger *e* working in a

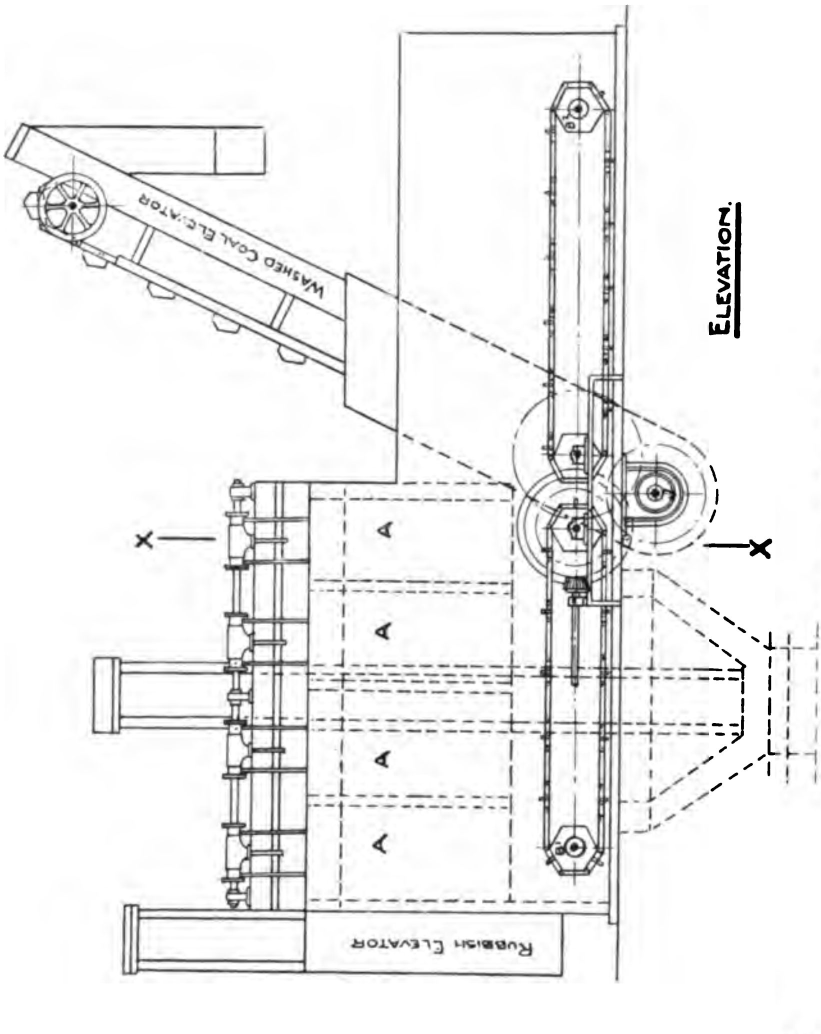


Fig. 410.—The Sheppard Fine Coal Wash

cylinder. The dirt finds its way at *c* into the lower portion of the tank, in which it settles, and is dealt with by the worm conveyor at the bottom, which conveys it to the rubbish elevator. The lighter coal flows away to the left, over the

screen surface GG, where the slowly-revolving brush H sweeps the nuts over the shute bb. The finer coal passes through the screen, and settles down to the bottom of the left-hand compartment of the tank, where the worm f conveys it to the washed-coal elevator D (*see fig.* 407, *page* 662), which raises it either into hoppers or

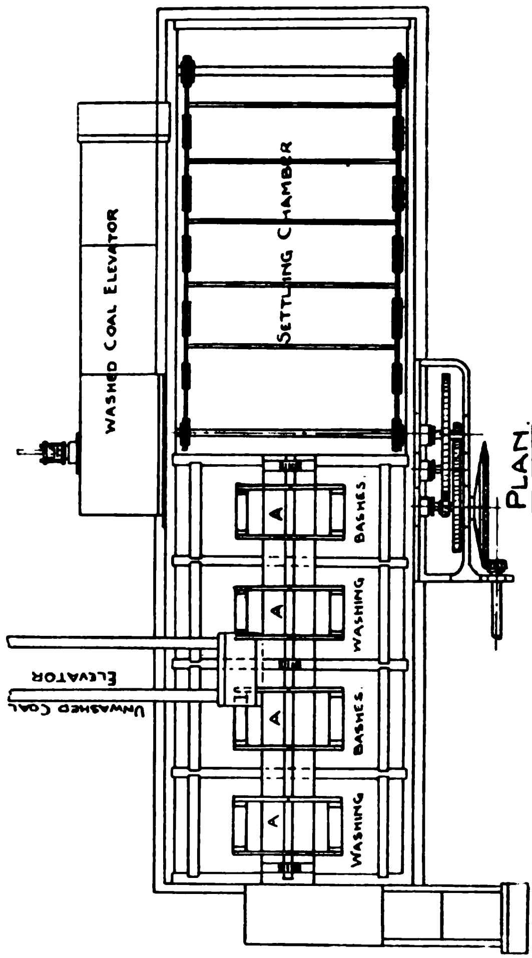


Fig. 411. Plan of the Sheppard Fine Coal Washer.

trucks, for the supply of the coke ovens. The course of the water in the washer is shown by the arrows in the section, fig. 408. (*See page* 663.) Passing with a vertical pulsation through the coal to be washed at aa, it gradually flows away to the left, under

the revolving brush *H*, through the screen *GG*, down towards the bottom of the smaller compartment, to ascend again on the other side of the vertical division, and through the valves *ggg*. At each upstroke of the plunger the water is drawn through these valves, and at each downstroke it is forced up through the coal to be washed and away to the left, as indicated.

Figs. 409 and 410 (*see pages* 664 *and* 665) and fig. 411 represent the fine washer. The coal is raised by the usual type of elevator, and delivered into the bashes, of which, in this case, eight are shown, arranged back to back, AAAA. The coal is washed in boxes made with steel-plate sides; the bottom is formed of cast-iron grating with perforated copper plates. A rapid pulsation motion is imparted to the boxes, about two hundred per minute, which has the effect of separating the coal from the dirt, and whilst the former flows over at HH and collects in the settling chamber, the latter passes away at DD into the inner portion of the washer immediately under the boxes, thence to be conveyed by the worm conveyors to the rubbish elevator. Water enters by the two pipes AA (*see fig.* 409), the direction of flow being over the sides of the boxes at HH, carrying with it the washed coal into the outer division of the tank, where the coal settles, and is conveyed by means of the endless scrapers to the collecting pit at the bottom of the washed-coal elevator. The water is returned to the machine and used over again.

The makers of the Sheppard washer claim that there is no appreciable loss in the process, which is entirely automatic, and that all the free impurities are removed. That is as much as the most perfect system could accomplish, because no method of washing can, by any possibility, remove impurities that are not free without removing the coal at the same time. They claim that the ash is reduced to 1·75 per cent in the coal, and that, as a rule, the washed coal does not contain more than 1 per cent above the fixed ash.

A Scotch mining engineer, who prepared some notes for the Mining Institute of Scotland, stated that the Sheppard coal washer removed only 39·9 per cent of the dirt in the coal. This authority (Mr. Cowan) said that the Sheppard coal washer left 19 hundredweights of dirt in every hundred tons of washed

coal; but the Robinson coal washer had an unfortunate pre-eminence of leaving 2 tons 6 hundredweights 2 quarters in each hundred tons of washed coal. Verily the claims made for some of these coal-washing arrangements are hardly so glowing when submitted to the test of an impartial critic. The most that we can say of the Robinson and the Sheppard methods is that they are probably the best applications of a system of coal washing which, under the most favourable circumstances, can only be very partially effective, and our duty is fairly well fulfilled by the foregoing descriptions and illustrations.

We pass away from systems that cannot grasp the right principle, and enter the domains of our continental friends, who have made the most thorough study for considerably more than one generation of coal washing. We of the United Kingdom were a good deal spoiled in the early days, because all the coal that was considered suitable for coke-making was really so admirable in quality that there was no necessity to do anything with it except to place it in the coke oven, and the result was, in its day and generation, the best coke in the world. And even when we did commence to do a little in coal washing it was a very trivial operation; but on the continent of Europe nature has been less kind to the mining regions, and whatever else the seams of coal possess, they are rich in impurities which have to be removed to make the coal anything like a valuable commodity. The writer was fortunate in making the acquaintance, some years ago, of the late Mr. Soldenhoff, a Belgian expert who settled in South Wales, and who probably knew as much of coal washing in its higher branches as any man of his time. The special feature of all these continental methods which strongly impresses the citizens of the Old Country is the subdivision of the coal; without that subdivision thorough efficiency is impossible; in that subdivision all our English systems are deficient; by that subdivision all the continental arrangements attain a degree of success which really is the best proof of the wisdom of the elaborate arrangements made in all cases.

In practically all the arrangements adopted in continental practice, which, perhaps, represent the highest degree of excellence attained in coal washing, the jigging type of washer is employed. In this appliance a rapid pulsating movement is

imparted to the water, varying in the amount and rapidity of the movement with the size and nature of the material to be dealt with. Briefly, the principle is this: The unwashed coal is deposited upon a perforated plate or grid submerged some few inches below the surface of the water in the washer. The pulsating movement, provided for in the manner to be described in detail later on, is so contrived that the water has a quick upward movement through the mixed coal and dirt, followed by a comparatively slow downward movement. During the upward movement the lighter coal, at each successive pulsation, is raised to a higher level in the mixed deposit, whilst the dirt, being heavier, tends to remain below. Similarly, during the downward movement of the water, the heavier fragments settle first whilst the lighter coal lags behind. In this way the coal and dirt are gradually separated into two distinct strata, the upper one being washed coal which, in due course, flows away at the proper outlet, the lower stratum of dirt finding its way to the bottom of the washing tank, there to be removed by worm conveyors or other means.

The well-known washers of the Humboldt Engineering Company, Messrs. Evence Coppée, and Messrs. Simon-Carvès Limited (Baum's system), representing some of the best types of coal-washing plant at work at the present time; all employ the jigging or pulsating machine in one form or another.

Our purpose will be amply served if we describe in detail the operation and construction of the two last named, that of Messrs. Evence Coppée Limited and the Baum washer.

THE EVENCE COPPÉE COAL-WASHING PLANT.

In the modern Coppée coal washers the plant comprises shaking and revolving screens for sizing the coal; the washers, which are described as nut washers for the larger sizes, and feldspar washers for the finer sizes of coal; elevators, and the disintegrating machinery. Both the nut washers and the feldspar washers divide the unwashed coal into three parts—namely, clean coal, clean shale, and mixed coal—that is, pieces which consist partly of coal and partly shale. There is thus a minimum quantity of material to be crushed and re-washed, instead of it being necessary to re-wash the whole of the shale. The intermixed coal and shale—intergrown coal, as it is some-

times called—is crushed and afterwards re-washed to effect the perfect separation of the coal and dirty material.

The following is a description of a Coppée washery, designed to deal with 1000 tons of coal in ten hours, for which, together with the drawings on fig. 412 (*see sheet* 22, *between pages* 670 *and* 671), we are indebted to Messrs. Evence Coppée. The coal is tipped by revolving tipplers **A** on to shaking screens **B**. The tubs run into the tipplers and out again by gravity. There is also an unwashed coal hopper **D**, capable of holding about 300 tons, from which it is elevated to the shaking screens **B**. The screens divide the coal into two sizes—namely, lumps above $1\frac{1}{2}$ inches round holes, and small coal under $1\frac{1}{2}$ inches.

The small coal falls directly into the unwashed coal pits **E**, and the larger coal is crushed to $1\frac{1}{2}$ inches before joining the small coal in the pits **E**; from here it is taken by the elevator **G** to the classifying screen **H**, which is placed on the top floor of the washery building, and which divides the coal into four sizes—namely, nuts, $1\frac{1}{2}$ inches to $\frac{13}{16}$ inch round holes, washed in the nut coal washers; peas, $\frac{13}{16}$ inch to $\frac{3}{8}$ inch round holes, washed in the nut coal washers; small, $\frac{3}{8}$ inch to $\frac{3}{16}$ inch round holes, washed in the feldspar washers; duff, $\frac{3}{16}$ inch and less round holes, washed in the feldspar washers.

All the washers separate the coal into three products—clean coal, clean shale, and pieces partly coal and shale (intergrown coal).

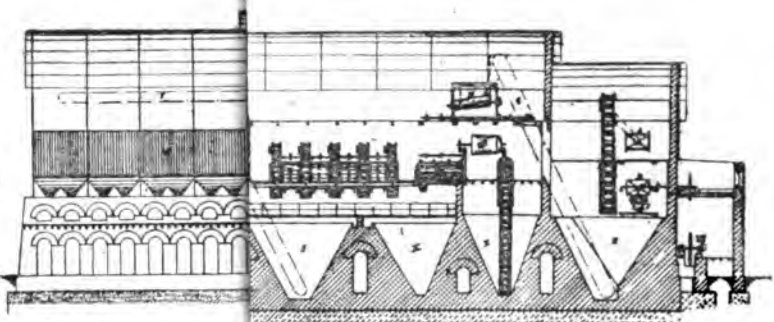
The washed nuts and peas are sent by a water trough either to fixed draining sieves, and stored in bunkers, to be sold as washed peas and nuts, or to the revolving draining screen, from which they fall into a disintegrator. The small coal and duff, washed by the feldspar washers, is also conveyed by water troughs to a perforated draining elevator, after which it joins the crushed peas and nuts. Finally, the mixture is conveyed by an elevator and scrapers to the small-coal bunkers shown on the extreme left of the elevation views in sheet 22.

The mixed coal from the nut coal washers—that is, the pieces consisting of partly coal and partly dirt—is crushed by a diamond-tooth roll crusher, after which it joins the intergrown or mixed coal from the feldspar washers. This mixture is elevated to a revolving screen, which makes two sizes, each of which is re-washed in feldspar washers.

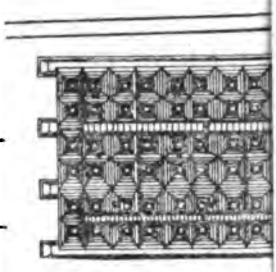
oal per hour

C D

I



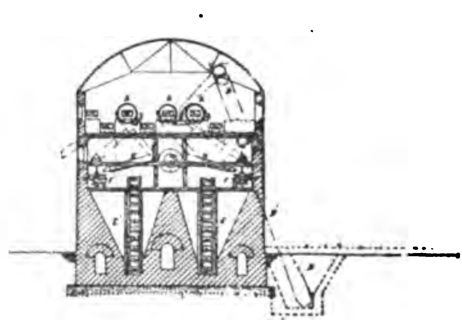
Plan Sectio



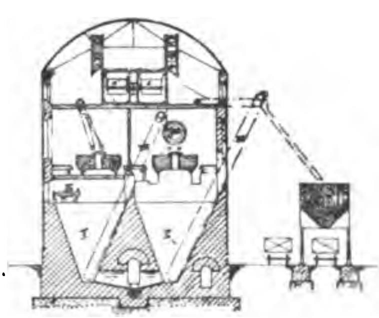
C

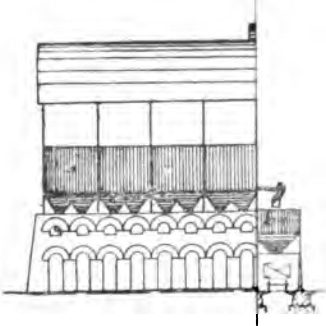
L

Section IV



Section RS





The nut washers, intended for the larger sizes of coal, are divided into two compartments, communicating below. (*See figs.* 413 *and* 414.)

The front, or washing compartment *A*, is 4 feet long and 3 feet wide, and is provided with a perforated strainer, slightly inclined from front to back. The second, or piston compartment *B*, is slightly smaller, being 3 feet 7 inches long and 3 feet wide, and is that in which the piston plays. The water is introduced from the back, below the piston, and is regulated by a valve *V*.

In the front of the washing compartment, about twelve inches above the strainer *S*, is an opening *W*, the length of which is equal to the full width of the machine, and through which the washed coal floats away continuously in a stream of

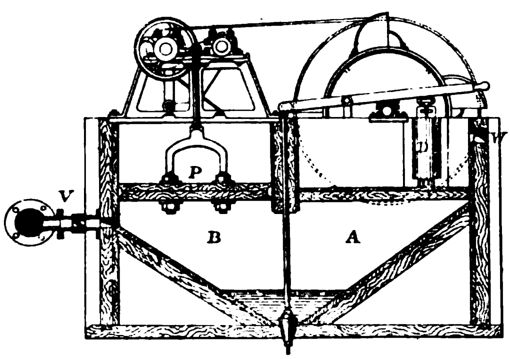


FIG. 413.

SECTION OF THE NUT WASHER, SHOWING THE WASHING COMPARTMENT A AND THE PISTON COMPARTMENT B.

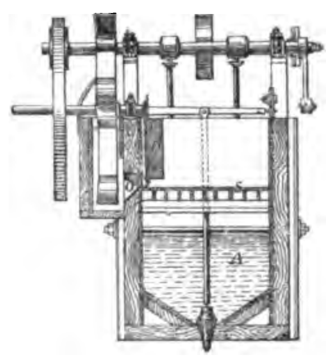


FIG. 414.

SECTION OF THE NUT WASHER THROUGH THE WASHING COMPARTMENT.

water. The piston *P* is secured to two piston rods, coupled to two cranks fixed on a horizontal shaft, which receives its motion by means of a cranked lever from a disc crank. This disc has a dovetailed groove to receive the crank pin, which may be adjusted at will and shifted to any point on its diameter, consequently giving more or less eccentricity. The shaft carrying the disc crank also carries a pulley giving motion to the system. The speed of the pistons is from 60 to 75 strokes per minute, and is made to vary in the inverse ratio of sizes. The length of the stroke is also varied from 1¾ inches to 4 inches, and is in the same ratio as the size of the material to be washed.

Before closing the description of this washing machine, it will be well to draw attention to what may be considered the most interesting part of it—namely, the manner in which the shale is drawn off continually and automatically from the machine. It will be noticed that on the right-hand side of the machine, as shown in fig. 413 (*see page* 671), there is a small cylindrical compartment *D* affixed to the side of the casing. This compartment is 10 inches wide by 6 inches deep, and starts above the level of the strainer, so as to leave a free space between the strainer and the lowest end of the compartment of about 3 inches. It is open at both ends, and is provided with an opening *O* communicating with the outside of the machine. It is through this opening the shale is ejected. The opening is situated about 6 inches from the strainer.

It is an accepted fact that when coal and shale are immersed in water and are being separated one from the other, according to their specific gravities, in the washing machine, as described, they will be subjected to the same law as that which governs two liquids of different specific gravities in a communicating tube—that is, that their respective heights, calculated from the line of separation, will be in inverse ratio of their specific gravities.

If now it is supposed that one branch of the communicating tube is represented by the front space of the washing case above the strainer, and that the other branch of the same tube is represented by the shale compartment, as described above—and also that the separating line of shale and coal is a horizontal plane passing through the lowest end of the shale compartment, and taking into account the specific gravity of coal in some cases as being 1·3, and of shale as being 2·3—it will be seen that the shale will rise in the shale department, in obedience to the physical law above referred to, in order to balance the bed of coal reckoned from the separate line to the level of the opening through which the washed coal passes out of the machine. This is so during the state of rest in the washing machine, upon the upstroke of the piston. The conditions are, however, altered when the downstroke commences, by which the state of balance just described is destroyed; part of the shale is expelled through the shale opening and part of the coal through the opening in front of the machine.

The height that the shale opening should be above the strainer can be determined mathematically, on knowing the relative specific gravity of the coal and shale.

To meet the practical working of the washing machine, and not to make the machines so scientifically exact, the inside of the shale compartment is furnished with a slide, or register, which may be lowered or raised at will, in order to regulate the height of the shale in the shale compartment.

A washing machine of the kind described is able to wash from 4 to 5 tons per hour. The coal washed in these machines is afterwards drained, and subsequently passed through a revolving screen, or over a reciprocating table, or taken up by a perforated elevator.

FELDSPAR WASHING MACHINE.

This machine (*see fig.* 415) is also divided into two compartments by means of a longitudinal partition. These compartments communicate with one another at the bottom

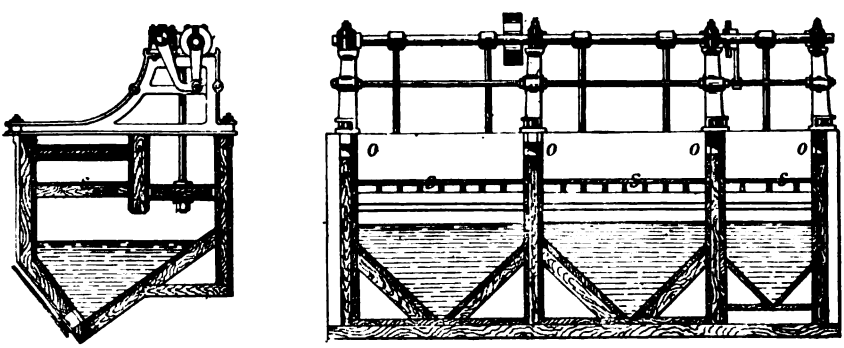


FIG. 415.
THE FELDSPAR WASHER.

of the casing; the compartments in which the pistons are placed are smaller than those containing the washing strainers. In the direction of its length the washer may be divided into two or three compartments; in the case of two compartments it is divided equally, but in the case of three the first two may be of the same length or the third may be shorter.

The fine coal arriving from the pointed boxes reaches the machine through the opening *O*, situated at the end, and passing through the compartments separates from the shale by

the force of the law of gravitation. In the case of a machine of three divisions, in the last one the coal separates from the streaked coal and carboniferous shales, so that the machine effects not only the separation of the impurities from the coal, but also separates these impurities according to their relative specific gravity.

During the process of washing the shale falls through the bed of feldspar placed upon the strainer *S*, to emerge through apertures situated in the front of the washing machines at their lowest parts and provided with sluice valves.

The coal having passed through the washing compartments is transported by means of a trough to a basin generally placed on a lower level than the feldspar machines.

In these machines the pistons are actuated in similar manner to the machines for coarse coal by means of crank levers. The feldspar machines are used only for washing coal from ⅜ inch downwards to impalpable powder, and will wash from 3 to 3½ tons per hour. The speed of the pistons is from 130 to 150 strokes per minute, and the stroke varies from 1 inch to 1½ inches, according to the coarseness of the grain to be washed. The bed of feldspar is from 3 to 4 inches thick, and its size varies from ¾ inch to 1¾ inches, according to the size of the grain washed.

It is necessary to state that the specific gravity of feldspar is 2·6, being slightly higher than that of shale.

Fig. 416 (*see sheet* 23, *between pages* 674 *and* 675) represents a Coppée washery applied to the draining bunker system. The description is as follows:—

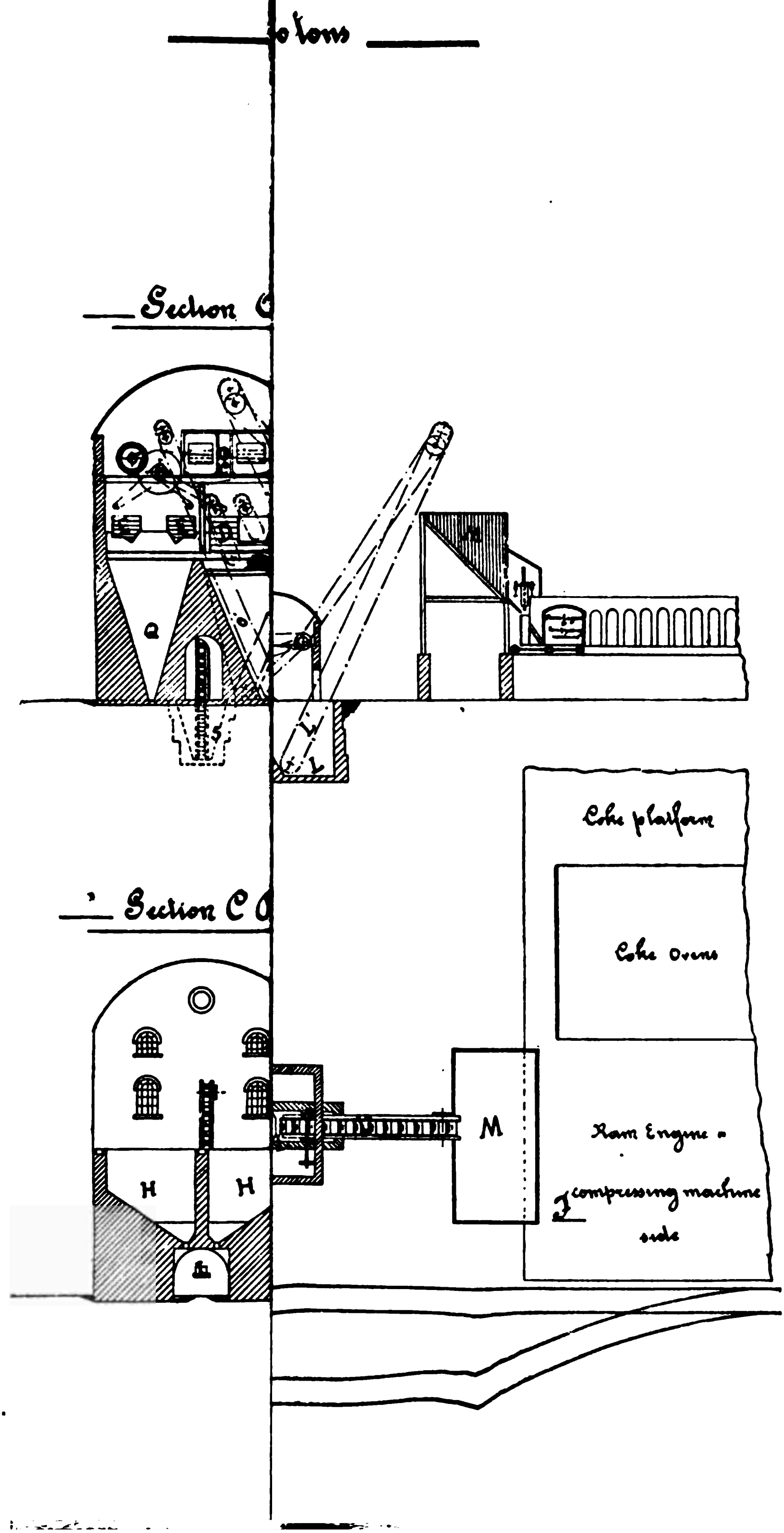
The washery is designed to deal with 70 tons per hour of coal from 2¾-inch round holes downwards.

The coal is supplied to the washery on hopper trucks running on siding *a*, and is unloaded into the unwashed coalpit **A**.

From the pit **A** the coal is admitted by a self-acting regulating damper slide to the unwashed coal elevator **B**, which raises the coal on to a double-balanced shaking screen **C**. This screen divides the coal into the following sizes:—

Cobbles: 2¾-inch to 2½-inch round holes, about 96 tons, to be washed in one nut coal washer **D**.

Treble Nuts: 2½-inch to 1⅝-inch round holes, about 177 tons, washed in the two nut coal washers **D′**.


o tons
Section C
Section C C
Coke platform
Coke Ovens
Ram Engine &
compressing machine
side
M
H
H
Q

Double Nuts: $1\frac{3}{8}$-inch to 1-inch round holes, about 96 tons, washed in the one nut coal washer D″.
Single Nuts: 1-inch to $\frac{3}{8}$-inch round holes, about 161 tons, washed in the two nut coal washers D‴.
Pearls: $\frac{3}{8}$-inch to $\frac{3}{16}$-inch round holes, about 89 tons, washed in the two feldspar washers E.
Duff: $\frac{3}{16}$-inch to 0-inch round holes, about 81 tons, washed in the two feldspar washers E′.
700 tons.

All the washers separate the unwashed coal into three parts—namely, washed coal, washed shale, and mixed coal (pieces part coal and part shale).

The cobbles, trebles, and doubles, washed by the four nut coal washers D, D′, and D″, are sent by troughs and water to the fixed draining sieves F, placed on top of the four bunkers O. In order not to break the coal by letting it fall into these bunkers, each contains a sort of screw trough, which leads the coal gently to the bottom of the bunker. From these bunkers the washed cobbles, treble, and doubles are loaded into trucks running on sidings *a* and *b*.

The singles, washed by the two nut coal washers D‴, and the pearls and duff, washed by the four feldspar washers E and E′, are sent by troughs and water into the six draining bunkers H. When properly drained the coal is taken from these draining bunkers on to a conveyor I, which carries it into the Carr's disintegrator K. The crushed coal falls into the pit L, from where the elevator L′ raises it to the compressing machine bunker M. This bunker holds about one hundred tons of coal, and if full in the evenings there is plenty of coal to go on with during the night at the ovens when the washery is not working.

The shale produced by all the washers is sent to the basin N, and raised by the elevator N′ into the two bunkers N″ placed on siding *a*.

The mixed coal produced by the feldspar washers is sent to the basin O. The mixed coal from all the nut coal washers is sent to the diamond-tooth rolls crusher P, and the crushed coal falls also into the basin O, from where the lot is raised by the elevator O′ into the revolving screen O″. This screen divides the mixed coal into two sizes, each to be re-washed in one of the two feldspar washers E″.

The washed coal from the mixed coal washers E″ is sent to the draining bunker H, and the shale is sent to the basin N.

The water from the nut coal draining sieves is sent to the mixed coal basin O.

The overflow water from the settling bunkers H and H′ and the basins N and O is sent to the slurry basins Q. The drained water from the nut coal bunkers and from the coking coal draining bunkers is collected into a small basin R, from where a small centrifugal pump raises it also into the slurry basins Q.

These slurry basins are V-shaped, and the settled slurry is run out at the bottom of each basin by a valve.

The slurry obtained is sent to a small basin S, from where it is raised by an elevator S′ to be either mixed with the coking coal, or to be taken into a truck on siding *a*, according to its value and cleanliness.

The valves at the bottom of the slurry basin are only opened occasionally—once or twice a day—according to the quantity of slurry produced.

From the last slurry basin the water is pumped up by a centrifugal pump T, to be used over and over again.

A culvert will, of course, be provided, in order to be able to empty any basin of the washery, if it should be required, but no water is sent away by it during the working of the washery.

All the machinery is driven by electric motors, placed in suitable positions, and by means of pulleys and belts.

THE BAUM COAL WASHER.

Mr. F. Baum, of Herne, Westphalia, who has devoted himself for the last quarter of a century to the questions of screening, sizing, and washing of coal, is responsible for what may be described, without fear of contradiction, as one of the most perfect systems of coal cleaning in existence. A mere statement of the fact that at the present time his firm has supplied washing plants having an aggregate capacity of not less than twenty-two millions of tons of coal annually, is in itself sufficient testimony of the excellence of the appliances and the manner in which they accomplish their work.

Formerly, the Baum system, like most others, consisted in

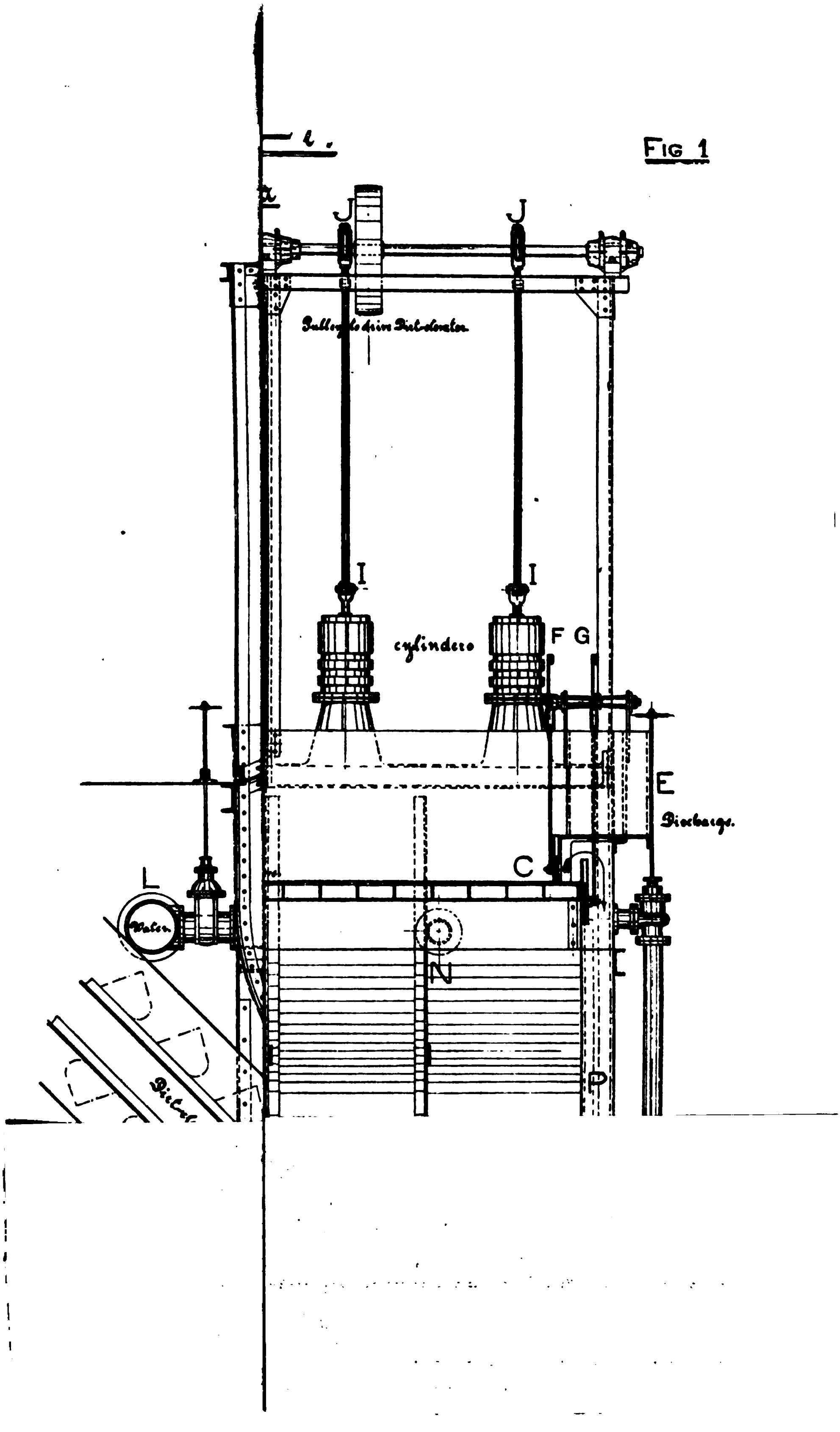


FIG 1

the preliminary classification of the coal into several sizes for the different washers. Latterly, Mr. Baum has adopted the principle of "wash first, then classify." The particulars given in the following pages, together with the illustrations and drawings, have been placed at our disposal by Messrs. Simon-Carves Limited, of Manchester, the representatives of the Baum washer in England.

The pulsating or jigging washer used in the Baum system relies upon compressed air, instead of a piston, to effect the pulsation of the water. The air, compressed to one and a half to two pounds per square inch, is delivered to the airtight compartment **A**, forming the left side of the washer, by the pipe **K**. (*See fig.* 417, *sheet* 24, *between pages* 676 *and* 677.) The admission is controlled by a piston valve **I**, worked by the eccentric **J**. It will be understood that during the time the piston valve admits the compressed air to the chamber **A**, the water on that side is rapidly depressed, simultaneously rising in the other compartment, where the washing takes place. When the piston valve closes against the admission of compressed air, it allows the air already delivered to escape into the outer atmosphere. It will thus be evident that whilst the water with the mixed or unwashed coal rises quickly, under the influence of the compressed air, it falls slowly, merely due to the inch or two of difference in the level of the water in the two compartments. In this way, the suction action, common to washers with a piston, is avoided, together with its objectionable features Instead of the coal and shale being drawn back in a more or less compact mass, by the suction effect of the piston in its upstroke, in the Baum washer the downward movement is so slow and gradual that as a matter of fact the smaller pieces of coal do not appear to sink at all, but to remain floating or suspended in the water.

The following details of the various parts, and description of a modern Baum washer, to deal with one hundred tons of coal per hour, will sufficiently explain the general working of the plant:—

DESCRIPTION OF THE BAUM WASHER.

Washing Machine (*see fig.* 417).—The Baum washer is one which washes from 0 to 3½ inches without preliminary classification.

In its general construction the washing machine on the Baum system is similar to that of the well-known pulsating washers, with much larger dimensions, but the essential difference is that the pulsating motion is obtained by the action of compressed air (4-foot water gauge), which acts upon the surface of the water in compartment A (*see fig.* 417, *sheet* 24, *between pages* 676 *and* 677) in such a manner that the movement is more elastic, but nevertheless more energetic than that obtained by a piston. The pulsating motion in the front compartment of the washing machine is quicker in the upward than in the downward movement. This is effected by a constant inlet of water into the compartment A at M and N. The pulsating motion combined with the movement of the water running through the washer is such that the coal, when passing into the front compartment of the washing machine on the top of the sieve BC, and going from D towards E, is classified in layers according to specific gravity—the heavier particles sinking to the bottom. The lower layer, composed of dirt and shale, is mechanically taken out at B and C through apertures of which the height is regulated by levers F.

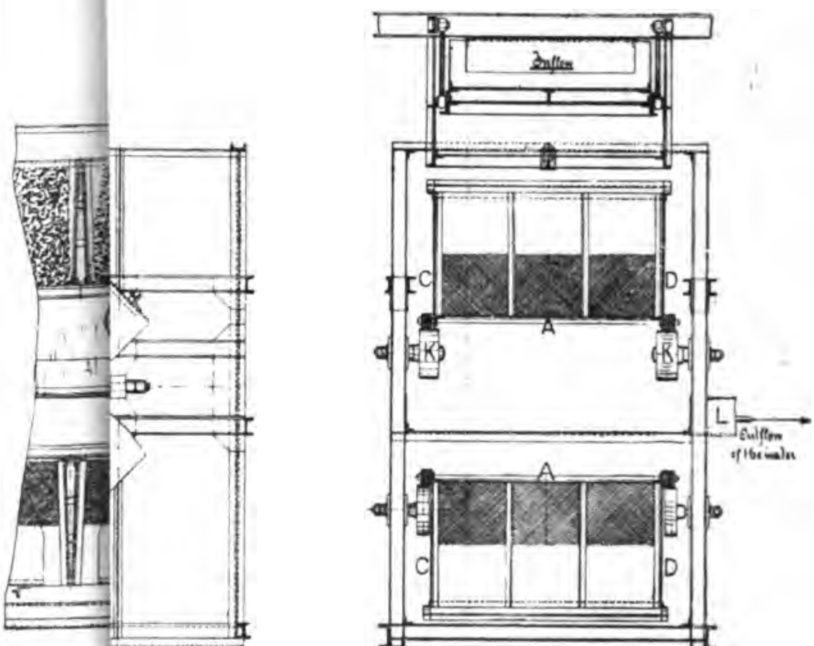
After having passed through these apertures, the shale has to pass over a dam of which the height is regulated by means of levers G.

Having passed through the apertures B and C (*see the arrows on the drawing*), the dirt falls to the bottom of the washing machine through the openings O and P. From there it is taken by two Archimedean screws H and an elevator Q with perforated buckets to allow the water to run off.

The admission and exhaust of the compressed air are regulated by sliding valves I, actuated by the eccentrics J. These valves are situated between the pipe K (conveying the compressed air) and the compartment A.

The coal is introduced by means of a current of water into the front compartment of the washing machine at D. The water necessary for the washing process is clarified and carried by the pipe L, which introduces it at M and N.

CLASSIFYING DRUM.—The exit of the washing water and of the washed coal is effected at E through a trough which leads the whole to a classifying drum of large diameter, and with superimposed sieves, where the screening is facilitated by a current of water, which forces the coal through the holes of the



C
D
A
K
K
L
Outflow of the water
A
C
D

different sieves of the drum. This peculiarity explains the good results obtained by this apparatus. The drum classifies into as many sizes as may be desired. Each size of coal is then led through troughs to the bunkers for loading into wagons, after having received a quick rinsing with fresh water, and a passage over metallic gauze, which allows the water to run off.

RE-WASHING OF FINE COAL.—The fine coal (under, say, $\frac{1}{2}$ inch) is taken with the washing water underneath the classifying drum by a centrifugal pump, which sends it to another washing machine similar to the one described above, where it is washed again before being sent to the draining conveyor.

SEPARATION OF INTERGROWN COAL.—If the quantity of coal contained in the intergrown coal and dirt is only insignificant, the intergrown coal is simply allowed to go away with the dirt. If, however, the quantity is important, the intergrown coal is separated from the dirt, and in that case the coal, after having passed through the first washing machine, is sent to a second washing machine similar to the first, in which the lower layer will be formed by the intergrown coal, which is recovered as described above.

SEPARATION OF THE DIRT OUT OF THE INTERGROWN COAL.—It is sometimes advisable to crush the intergrown coal in order to effectively separate the dirt from it. In that case the crushed intergrown coal is mixed with the fine coal before it enters into the last washing machine.

DRAINING PLANT (*see fig.* 418, *sheet* 25, *between pages* 678 *and* 679).—The draining plant is able to reduce the added moisture in the coal to such reasonable percentage as may be desired. At the same time it clarifies the washing water by extracting a great part of the slurry by filtration through a constantly renewed layer of fine coal.

This draining plant consists of an extremely strong conveyor, carrying about two tons of coal per yard. The conveyor is made with perforated plates A (*see fig.* 418) hinged one to the other, and carrying on the middle a double vertical partition B of perforated sheets, strengthened with angle irons, and slightly apart from each other to allow the water to run between them; and two upright sides C and D also perforated. The conveyor thus presents an aspect of a series of boxes hinged one to the other in the middle of the bottom.

The washing water comes with the fine coal on specially arranged swinging sieves of metallic gauze, which, as indicated (*see fig.* 418, *sheet* 25, *between pages* 678 *and* 679), allows the water, and the slurry, and the very fine coal to pass through, whilst the coarser coal slides down to the conveyor at H. The finer coal and the slurry, separated as just mentioned, then falls on top of the coarser coal from I to J.

The coal is now in the best condition for draining.

As the conveyor moves it passes over the supporting rollers K, the distances and the difference of height between which are calculated so as to let the conveyor bend under the load of coal between one roller and the other.

The effect of this sagging of the conveyor is to press the coal between the vertical partitions B when it arrives between the rollers, or above the lower rollers, and to open these partitions one from the other as it arrives above the higher rollers.

The coal is in this way submitted to a process of pressure and expansion, which compels the separation of the water from the coal.

This water, in passing through the layer of coarser coal at the bottom of the boxes, leaves a great part of the slurry on the draining conveyor. It is afterwards recovered at L, and sent through specially designed settling tanks, ensuring its thorough clarification. After clarification, the water is used over again in the washer.

REGULATION OF MOISTURE.—The percentage of water left in the coal may be regulated by the speed of the conveyor. The conveyor has a length of about twenty-two yards, and generally a speed of about eight inches per minute. If it is run quicker the percentage of water is larger, the coal having thus less time for draining, and *vice versa.*

SETTLING TANKS (*see fig.* 419).—The settling tanks are established in such a manner that the slurry still contained in the washing water, after its passage through the draining conveyor, is automatically and continuously recovered. In the latest plants there is only one settling tank of large diameter (33 feet diameter and 39 feet deep), which is constructed of iron, and supported by a brick tower outside the washer building.

In some plants the settling tanks are placed inside the washer building, on the same floor as the coal hopper. Their object is always the same, facilitating the deposit of the slurry by a sudden stoppage in the speed of the current of water.

The tank is the shape of a cone, point downwards. The water containing the slurry is pumped through the pipe E (*see fig.* 419) at the point A. It meets the shield B and is then compelled to cross the tank from the centre to the circumference, and conse-

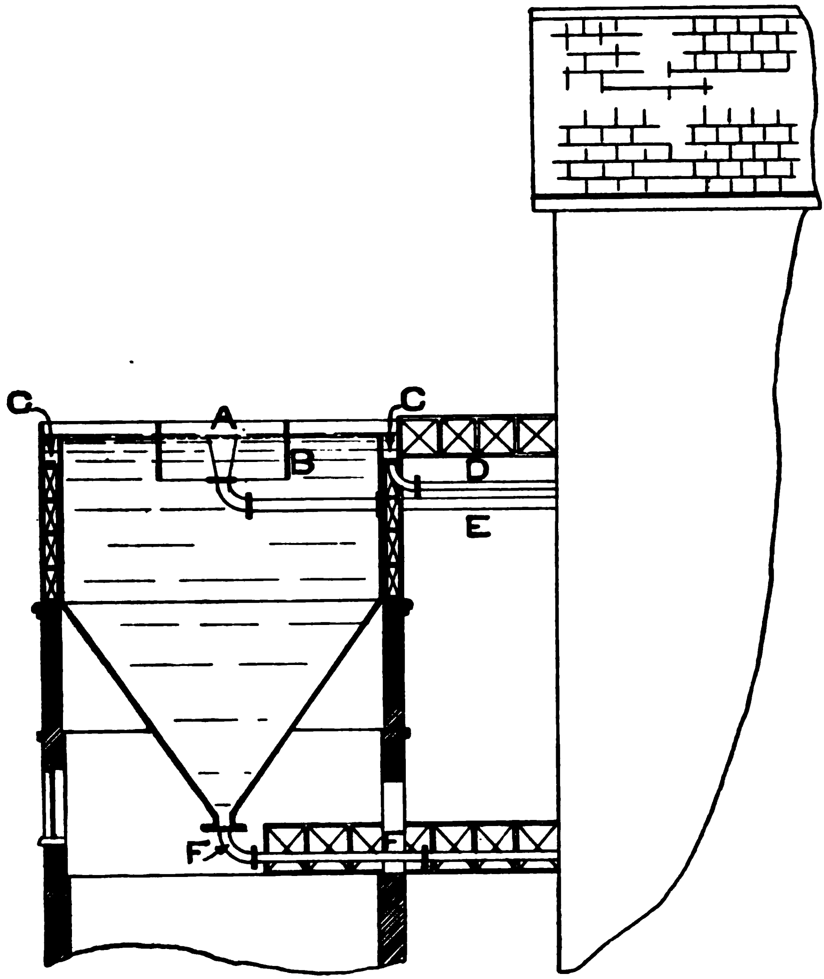


FIG. 419.
SECTION OF THE SETTLING TANK.

quently with a speed decreasing in geometrical progression, before it falls into the gutter C which surrounds the tank.

It is thus recovered in a clarified state in this gutter, and taken away by the pipe D to the washer.

Slurry Recovery.—The slurry, falling to the bottom of the tank, is continuously extracted in the form of a liquid mud through the pipe F, which takes it again to the draining pipe if it is clean, and where it remains with the fine coal, or if it is too dirty it is sent into tanks of small area, outside the washer, where it is collected and used when and where the colliery finds it advantageous.

Building for the Washer.—The washer is entirely self-contained in a building erected on columns above the railway lines. The construction is usually of iron filled in with brickwork. All the floors and gangways forming the storeys are made of wrought iron, with holes, allowing the man in charge to see from one floor to the other, thus facilitating the supervision of the plant.

The washer proper is situated at the top of the building, underneath coming the draining plant, pumps, and motors, then the settling tanks and hoppers directly above the railway lines.

The coal being once brought to the washer at the top undergoes the process of washing, screening, draining, storing, and loading *without the necessity of repeated liftings with elevators*, and consequently with a minimum of manipulation, thus avoiding breakages, which increase the quantity of small coal.

Description of a Plant (*see figs.* 420, 421, *and* 422, *sheet* 26, *between pages* 682 *and* 683).—The coal washer erected at Gladbeck, in Westphalia, may be considered as a standard washer on the Baum system.

The coal is brought from the screening plant A through jigging screens B, passing everything under 3 inches into the hopper C. It is then lifted by an elevator D to the top of the washer building. It receives at E a current of water, which pushes it into the first washing machine F. The shale falls to the bottom of this washing machine, and is caught by an elevator with perforated buckets G, and dropped along shutes into the hopper H.

The washed coal is then conducted to the classifying drum I, which classifies into five, or as many sizes as may be desired. Each size is delivered into hoppers J by means of shutes K and spirals, which take the nuts without breakage up to the loading hoppers, each having a capacity of 50 tons.

The fine coal from 0 to ½ inch falls with the washing water into a centrifugal pump L, which lifts it into a second washing

machine **M**, where it is again washed, and the last traces of fine dirt extracted. The dirt is lifted by an elevator with perforated buckets **N**, and sent down to the hopper **H**. The fine coal leaving the second washing machine is carried by the washing water to the draining band **O**, which delivers it, with the desired percentage of moisture, into the hopper **P**, which has a capacity of 200 tons, where it is spread by means of Archimedean screws.

In some plants this fine coal is crushed at the end of the draining band by a disintegrator, situated above the bunkers **P**.

The washing water undergoes a second clarification in the settling tanks **Q** in the washer building.

The slurry continuously extracted through the bottom apertures **R** is conducted in the shape of a liquid mud to the centrifugal pump **S**, which pumps it again on to the draining band at **T**.

The clarified water is pumped through the centrifugal pump **U**, and sent back to the washer.

The settling tanks can be replaced by the one previously described, and placed outside the washer building. Such an arrangement gives more room for the fine coal bunkers.

The compressed air is provided by the rotary blower **V**.

The washed sized coal is loaded directly into the railway wagons by the shutes **X**, provided at **Y** with rinsing apparatus, and the washed fine coal is either loaded directly into the railway wagons or into the corves **Z**, situated at the level of the top of the coke ovens.

All the motors of this washer are electric, having a total power of 140 horse power.

This washer deals with 100 tons per hour of raw coal.

DIAGRAM.—We give a diagram (*see fig.* 423, *page* 684) showing the process of the different operations in the Baum washer. The alternative scheme shown in dotted lines and italics is applied when it is advisable to extract the intergrown coal separately and re-wash it after crushing, before sending it into wagons for sale, or for use by the colliery for their boilers.

ADVANTAGES OF THE BAUM SYSTEM.

Having thus described the apparatus and plant of the Baum washer, the advantages claimed for this system as compared with those having preliminary classification are easily seen, namely :—

1. Reduced first cost of the washing plant. Generally only one or two washing machines, or—in exceptional cases—three, are necessary, whereas in other systems, where preliminary classification is necessary, a large number of these machines is always required.

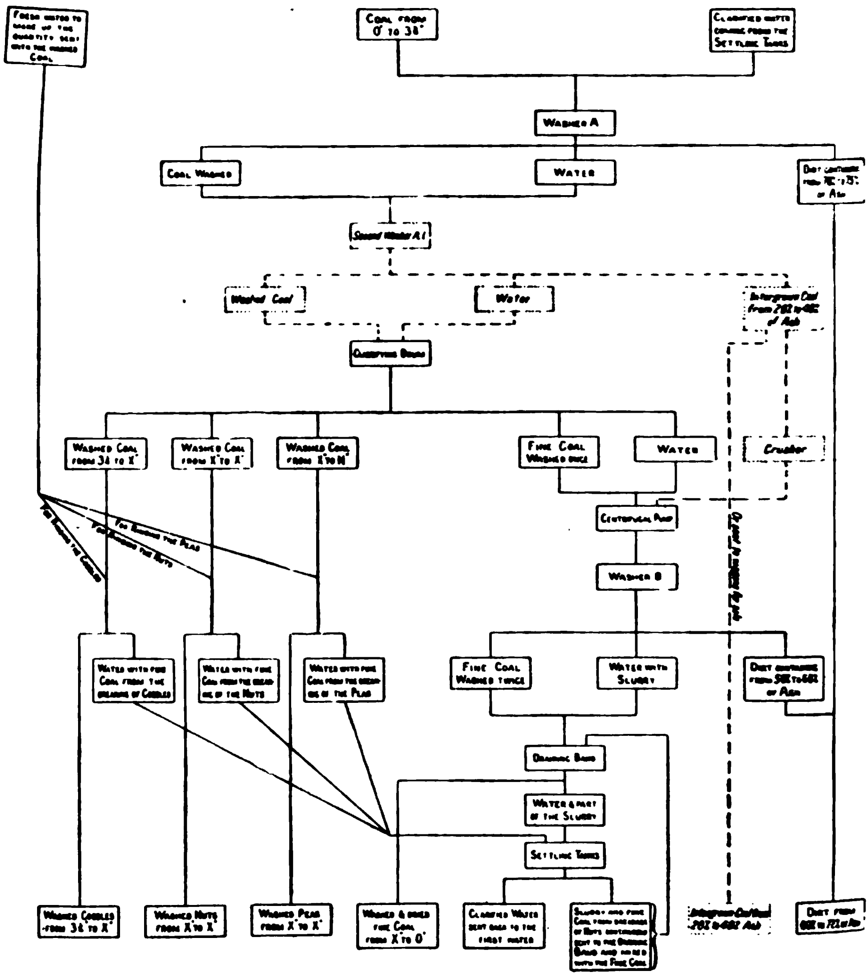


FIG. 428.

2. Saving of about 30 per cent of ground space.
3. Saving of about 30 per cent of driving power required.

4. Saving of about 25 per cent of labour, owing to the smaller quantity of apparatus requiring supervision.

5. Saving of about 50 per cent in upkeep, due to the diminished quantity of apparatus and motive power, and also to the suppression of pistons and shocks.

6. The coal being classified just before loading into wagons is exactly sized, which is not the case when the washing, etc., is done between the sizing and the loading.

7. Minimum increase in small coal by washing.

8. Complete avoidance of loss of coal as slurry, and that in spite of being able to wash the very fine coal dust.

9. Proper drying of the fine coal, and exact regulation of the percentage of moisture.

EFFICIENCY.

We may cite, as an instance, the washer at the Rhein Elbe Colliery, belonging to the Gelsenkirchen Colliery Company, Gelsenkirchen, in Westphalia.

This installation has two washing machines; the first washes all the coal under $3\frac{1}{4}$ inches (quantity 100 tons), and the second washer deals a second time with the fine coal under $\frac{3}{8}$ inch (quantity about 50 tons). A duplication of this installation is also erected in the same building, bringing the total washing capacity up to 200 tons per hour.

The washed products are sized as follows:—

Nuts I.	... ...	$3\frac{1}{8}$ inches	— $1\frac{3}{4}$ inches.
Nuts II.	... ...	$1\frac{3}{4}$,,	— $1\frac{1}{16}$,,
Nuts III.	... ...	$1\frac{1}{16}$,,	— $\frac{11}{16}$ inch.
Nuts IV.	... ...	$\frac{11}{16}$ inch	— $\frac{3}{8}$,,
Fine coal	... ...	$\frac{3}{8}$,,	— 0 ,,

The percentage of ash in the coal going to the washer is 15 per cent to 18 per cent; that of the coal leaving the washer is 3 per cent to 4 per cent in the nuts, and from 3·5 per cent to 5 per cent in the fine coal (washed twice), including the slurry. The dirt extracted from the first washing machine contains 70 per cent of ash, and the dirt extracted from the second washing of the fine coal contains 53 per cent of ash.

The quantity of this last fine dirt from the second washing of the fine coal is only 14 per cent of the total quantity of the dirt sent to waste from the washer, so that the bulk of the total dirt extracted from the coal in the washer contains an average of 67·6 per cent of ash. The total quantity of dirt extracted

by washer is 18 per cent of the coal going to the washer, and this dirt contains less than 2 per cent of its weight of free coal, bringing the loss to under 0·36 per cent.

At the Brefeld pit, in the Saar district, the percentage of ash in the coal going to the washer is 33 per cent; that of the coal leaving the washer is 8 per cent in the nuts, and 8 per cent in the fine coal, including the slurry.

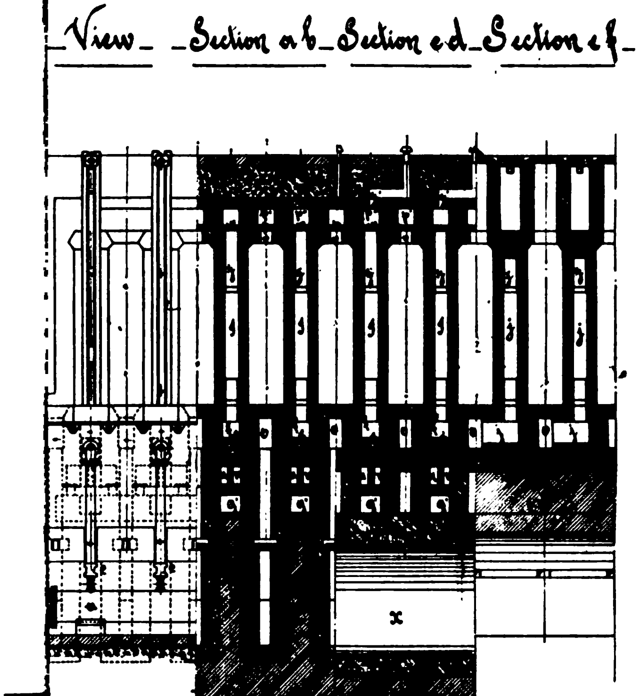
The intergrown coal is separated, and contains 25 per cent to 30 per cent of ash, the quantity of which is about 12 per cent of the total quantity of the coal. This intergrown coal is used in the colliery boilers. The dirt (large and small) contains an average of 72 per cent to 74 per cent of ash.

PLANT FOR THE MANUFACTURE OF COKE.

As we remarked at the commencement of this chapter, the old order of things, so far as the manufacture of coke in this country is concerned, is passing away. Old prejudices have been overcome, because, unless a prejudice has something substantial to support it and keep it alive, it must, in course of time, die out and disappear before the advances and attacks made against it.

The manufacture of coke in the beehive oven is comparatively simple; but simplicity is not the end and aim of coke manufacture, more especially when that simplicity carries with it no other advantages, but rather tends in the direction of costliness and waste. Energy is not the only valuable product of coal; the abundant store of heat and work is accompanied by a wealth of chemical products, the extraction of which has well-nigh revolutionised the chemical industry; indeed, certain branches of that industry owe their very existence to these products of coal.

It has been found that in the conversion of coal into coke, the bye-products, as they are termed, have a value almost equal to the fuel itself. Indeed, it has even been remarked that the coke is the bye-product, and that the distillation of the coal is carried on for the purpose of obtaining the valuable chemical products. With this particular aspect of the question we are not concerned for the moment; the great iron and steel industry, so closely allied to the mining industry, relying upon the latter, indeed, for its existence and successful



ye Product Coke Oven

OR WITHOUT RECOVERY

YE-PRODUCTS.

operation, requires in its processes coke of a particular quality. Formerly it was supposed that only beehive coke possessed the properties and presented the quality required. Competition, however—and there is no more stimulating incentive to industrial progress—has demonstrated that improved processes can not only produce coke of equal value at less cost, utilising the valuable products formerly wasted, but that these improved processes can produce excellent coke from coals formerly regarded as unsuitable for coke manufacture.

The pages of this volume scarcely lend themselves to the detailed consideration of an industry so important as coke manufacture; indeed, a volume of larger dimensions might well be devoted to this subject alone. With the increase of coke manufacture by modern processes at modern collieries, however, before us, we feel that, before concluding, some reference, however brief, must be made, at least, to the mechanical equipment of the colliery for coke manufacture, of which the subject we have just concluded—coal washing—must be regarded as the preliminary stage.

THE COPPÉE BYE-PRODUCT COKE OVENS.

The Coppée bye-product coke ovens, illustrated on sheet 27 (*between pages* 686 *and* 687), have a capacity of from 35 to 45 tons per oven per week, and may be worked either as bye-product recovery or non-recovery ovens, as desired. The ovens into which the fuel is charged are long, narrow, vertical chambers—a longitudinal section through the oven is shown in fig. 1 (*sheet* 27)—surrounded by a system of flues through which the hot gases circulate to carry out the carbonising of the coal. Instead of the large mass of fuel, as in the bee-hive oven, the coal is so arranged as to be subjected to the action of the heat in the quickest and most effective manner.

DESCRIPTION OF THE WORKING OF THE OVENS AS BYE-PRODUCT RECOVERY OVENS.

The gases escaping from the coal are taken from the oven by the vertical opening *h* (*see fig.* 1), which leads them by means of cast-iron pipes to the bye-product plant.

After the bye-products are extracted the gases return to the ovens by the two pressure pipes *a*, each placed in an outside gallery L, at each side of the oven.

From the pressure pipe *a* the gases are introduced into the side wall of the oven, which is divided into two equal parts by the separation *b* (*see fig.* 2, *sheet* 27, *between pages* 686 *and* 687), in the following manner:—

(The description for both sides of the ovens being the same, reference is made to the direction of the flames on one side only.)

From the pipe *a* the gases pass into the mixing tube *u*, on each side of the oven, by means of a burner C (this burner is similar in construction to a bunsen burner), where a part of the air necessary for the combustion is mixed with it.

The mixture of gas and air is blown into the distributing flue *d* placed under the side wall of the oven, and from here it is driven through a certain number of slits *e* into the combustion chamber *f*, where it receives the other part of air necessary for a complete combustion.

This secondary air, heated by the foundations of the ovens, is carried through the opening *g* (*see fig.* 2) into the flue *g′*, and from here it is admitted to the two air chambers *m* by two dampers *k*. One of these air chambers *m* supplies the secondary air to the front part of the oven, and the other to the middle part of the oven, by means of slits *n*, one for each gas slit *e*.

From these slits the secondary air passes into the combustion chamber, where it meets the gas for complete combustion.

From the combustion chamber *f* the flames ascend uniformly on the whole length of the side wall through the vertical flues I, meeting in the horizontal flue *z* placed on top of the side wall. From here they descend by the three vertical flues *j*, which lead into the flue *o* under the floor of the oven. The floor of the oven is thus heated on both sides and on its entire length before the heat leaves the oven by the opening *q*, from where it passes into the main collecting flues *x* leading to the boilers and chimney.

All the regulation of the ovens takes place in the gallery L. Supposing the oven is cold in the middle at R, and too hot at S, if the quantity of gas is sufficient the heat can be brought to that place R in two ways—first, by opening the primary air inlet at the bunsen C more air will be carried in by the gas, the velocity of the mixture will increase in the distributing flue *d*, causing a bigger pressure at the end of the flue *d* than at the commencement, and consequently supplying at that place more

of the mixture of gas and air; secondly, by opening more the secondary air damper *k*, supplying air to the front part of the combustion chamber *f*, and by closing more, at the same time, the one supplying air to the back part of the combustion chamber *f* (the draught in the combustion chamber *f* being the same), it always draws the same quantity of mixture, which is more gas and less air at R, and less gas and more air at S; consequently the oven will get hotter at R and colder at S. The opposite takes place, of course, if the oven is cold at S and hot at R.

It may be suggested that the oven is cold at T, between R and S. This is, however, impossible, because the heat at T must always be the mean heat between R and S, as the pressure in the middle of distributing flue *d* is always the mean between the pressure at both ends.

The regulation can be carried on without leaving the gallery L, because from that gallery the gas can be seen burning in the combustion chamber *f*, and it is also possible to see into the flue *o* under the floor of the oven, and observe if the gases going into the main flue are completely burnt.

The dampers regulating the draught of each oven are also regulated in the gallery L. There are also spy holes on top of each side wall, where the working of the oven can be observed from the outside.

DESCRIPTION OF THE WORKING OF THE OVENS AS NON-RECOVERY OVENS.

In this case the vertical damper *y* is let down into the horizontal flue *z*, as shown in dotted lines, and the dampers *p* are opened. The gases escaping from the coal leave the oven through the openings *v* (*see fig.* 2, *sheet* 27, *between pages* 686 *and* 687) and pass through *p'* into flue *p''* placed on top of the side wall. (*See fig.* 1.)

The dampers *w* being also opened, the gases descend into the front part of the horizontal flue *z* (and air is admitted by the openings *z'*), and then descend by the vertical flues I into the chamber *f*. From here the flames ascend through the vertical flues I' into the middle part of the flue *z*, and the heat then follows the same course as described for the bye-product recovery ovens.

BOILERS HEATED WITH THE WASTE GASES OF COPPÉE OVENS.

(*a*) Trial made with three Lancashire boilers heated by waste

gases of thirty Coppée ovens coking in forty-eight hours at the Charbonnages de Ressaix-Leval-Peronnes et St. Aldegonde, at Ressaix, Belgium.

Coal put into ovens during twenty-four hours	87 tons.
Volatile matter contained in the coal ...	20 per cent.
Ash contained in the coal	7 per cent.
Water evaporated per twenty-four hours	106 tons.
Water evaporated per hour	4·416 tons.
Water evaporated per ton of coal put into the oven...	1·22 tons.*

(*b*) Trial made with two Babcock and Wilcox boilers heated by the waste gases of twenty Coppée ovens, coking in twenty-four hours.

Coal put into the ovens per twenty-four hours	91 tons.
Volatile matter contained in the coal ...	18·50 per cent.
Ash contained in the coal	6·35 per cent.
Water evaporated per twenty-four hours	130·68 tons.
Water evaporated per hour	5·44 tons.
Water evaporated per ton of coal coked	1·43 tons.

In bye-product ovens the quantity of water evaporated by the latent heat left off from the oven is about one ton of water evaporated per ton of coal coked.

In the case of coal containing a great quantity of gas only part of the gas is used for heating the ovens; the surplus may, of course, be used for raising steam or for other purposes.

THE NEW SEMET-SOLVAY COKE OVEN.

We have to thank Mr. John H. Darby, of Brymbo, Denbighshire, for the illustrations and detailed particulars which enable us to describe one of the most successful of modern coking processes.

The Semet-Solvay coke oven is of the horizontal-flued type, for which arrangement—as compared with the vertical-flued type—is claimed, as one important advantage, the fact that it is capable of being observed throughout its length at any time, whereas the oven with vertical flues cannot be so examined,

* This quantity would be increased to 1·50 tons of water evaporated per ton of coal if the ovens were drawn regularly during twenty-four hours instead of during ten hours only.

and, consequently, any leakage of gas from the oven into the flue is much more likely to remain undetected. (*See fig.* 424.)

Both the condition of the flues and the combustion of the gas in the same may be observed throughout their length, the gas and air entrances being controlled from outside. Too much importance cannot be attached to the fact that sufficient and equal distribution of the heat is in this way under observation, and that the heat in each flue is under separate and immediate control.

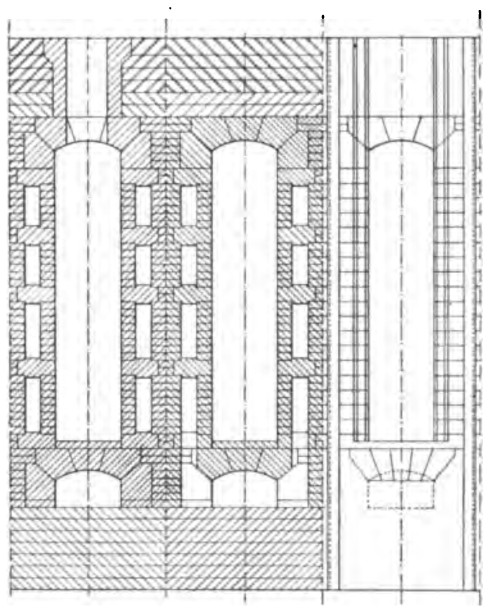


FIG. 424.

CROSS SECTION OF THREE OF THE SEMET-SOLVAY OVENS.

The heating flues forming the side walls are built of perfectly-formed small bricks of a special quality, which experience has shown to be well adapted for the work, rubbed down and bedded in their places with fine clay cream joints.

The bricks dividing the flues are rebated into these, as well as into each other, longitudinally, the whole forming a perfectly sealed system that cannot be disturbed, and one which presents to the wall of coal in the oven the largest possible equally-heated surface.

These flues, in which the combustion of the gas takes place,

and which in other systems of ovens are actually built in and form part and parcel of the main supporting walls, are here absolutely independent of the main structure of the oven, and carry none of its weight, forming, in fact, a veritable lining, which can be renewed, when necessary, without touching the surrounding walls. More than this, in no case is it necessary to lay off, even temporarily, any oven, except the actual oven to be repaired; the ovens on either side can be maintained at full heat.

The construction of the oven, it is claimed, is as tight and free from leakage as most gas retorts, and is, in short, admirably adapted not only for the recovery of the maximum of bye-products from a given quantity of fuel, but also for the production of illuminating gas.

The ovens, generally erected in batteries of twenty-five each, are chambers covered by strong arches carried on solid sidewalls. They are generally 30 to 33 feet long and 5 feet 8 inches to 7 feet high. The width varies according to the class of fuel it is proposed to treat, from 13 to 20 inches. The arrangement is such that all unnecessary loss of heat is avoided, and the combustion of the gas in the flues is under such complete control that an even heat throughout the oven is assured, and consequently the coking of the charge proceeds regularly and rapidly. It is to ensure this that the cover over the chamber arches has been made so thick, and the oven doors have been carefully designed to avoid any cooling at the ends of the oven. All possibility of air leaking into the ovens is most carefully guarded against, and the coke when discharged shows no trace of combustion, which proves that the oven is air-tight.

The dividing walls carrying the main structure of the oven are not pierced by any flues, but form a solid support to the heavy brickwork overhead. They maintain a temperature to all intents constant and unaffected by the loss of heat in the oven when being freshly charged, and possess therefore considerable recuperative value. To this fact, as well as to the practically-continuous heated wall presented to the charge, is due the great advantage of the oven—namely, the largest yield per unit of outlay.

The system of ironwork ties and supports in a battery of

Semet-Solvay ovens is very thorough and substantial. The door frames are heavy castings, extending to within touch of each other, and held by buckstaves and strong tie-rods in such a way as to form a complete shell of ironwork enclosing the battery.

The output of the ovens varies from 40 to 50 tons of coke per oven per week, according to the width adopted, and the cost from £800 to £1000 per oven, according to the requirements of the site, the extent to which the recovery of bye-products is carried, and the general equipment of the plant with labour-saving devices and electric power distribution. This cost is inclusive of everything necessary to start and work the plant.

One aim of the Semet-Solvay system is to avoid deposits of carbon and tar in the gas off-take pipes, and to effect this dry mains and dry connections into the same are never used, because they give rise to these deposits and consequent loss of time and labour in cleaning, as well as to a loss of recoverable bye-products. The gases leaving the oven are conducted by the shortest possible pipe connection direct into a hydraulic main, through which a large circulation of liquor is maintained.

After leaving the hydraulic main, under the influence of an exhauster, the gases are further condensed and the remainder of the tar and liquor extracted, and they are then returned under a slight pressure to heat the oven flues by means of the burners of suitable construction. The heated gases pass through the side flues carried horizontally along the sides of each oven, thence through the flue under the oven floor to the chimney flue. A constant supply of gas and air to each oven is ensured, and an even draught maintained by means of special arrangements. The surplus gas remaining after this purpose has been effected, and which is available for either power or light, amounts to about 40 per cent of the whole when coking good rich coals. It is capable of evaporating 1¼ pounds of water for every pound of coke made. The boilers should have from 60 to 130 square feet of heating surface per oven, according to the composition of the fuel. The ovens are charged with compressed slack through the doors, which may be made either to lift or hinged. The machines for compressing and charging

are shown in figs. 425 and 426, fig. 426 (right-hand side) being a side and fig. 425 (left-hand side) an end elevation, each with the charger in position for stamping. The arrangement may be explained as follows:—At a suitable point in the ram race, either at the end of the battery or in the middle between two batteries, girders are thrown across and roofed in to form a runway for the conveyor supplying slack and for the stamping machine, both of which are so placed as to be capable of serving the charging machines when brought into position underneath. The conveyor is a patented arrangement for distributing the slack at the rate of 40 to 60 tons per hour, in even layers over the length of the compression box of the charger, and being started it reverses itself automatically at either end, and requires no further attention until the box is full. Parallel with the conveyor works the stamping machine, travelling to and fro along the box and reversing itself automatically. The stamp is of a very simple and reliable design, carrying two stamp heads weighing from 2 to 2½ hundredweights each, and each falling from 45 to 55 times per minute.

The box in which the fuel is compressed consists of two strong plated sides that may be closed or opened, in order to control the width of the coal cake, by means of a system of patent eccentric gears. At the bottom of the box is the charging peel, flat on the top and having rack teeth underneath engaging in gearing. At the back of the box is a vertical thrust-plate fixed to and travelling with the peel. A charge having been stamped as described, the machine travels up to the oven to be charged, and a temporary door closing the front of the box during the stamping operation is removed. The sides of the box are then eased open by means of the eccentric gear, and the peel put in motion. The charge having been fully pushed in, the thrust-plate at the back is withdrawn by suitable gear, the oven door is closed over the back of the peel and fastened, when the peel is withdrawn, leaving the fuel charge inside the oven.

In every case where these machines have been applied the improvement in the quality of the coke has been remarkable, not only with good coking coals, but especially with some slacks not usually considered of good coking quality. Without

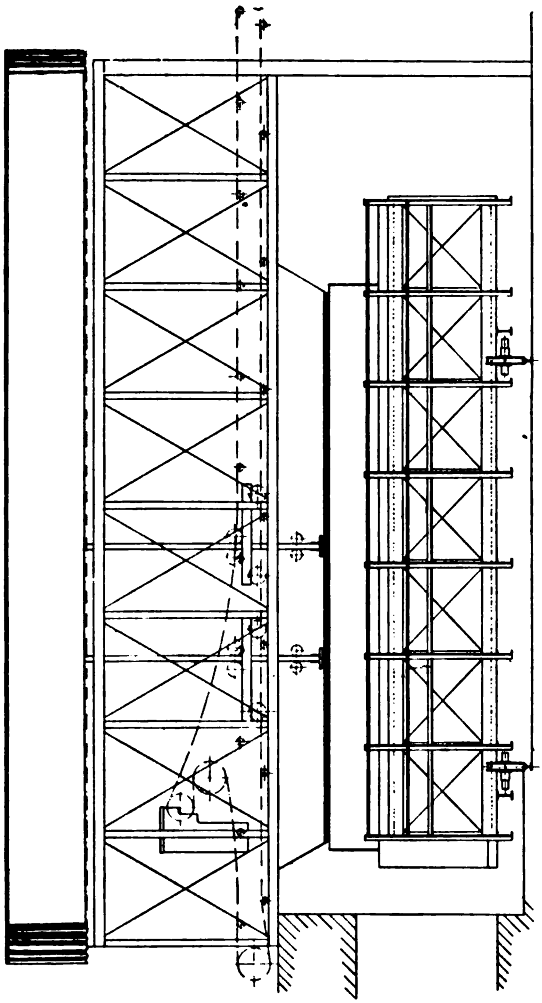


FIG. 426.
THE COMPRESSING AND CHARGING MACHINERY.

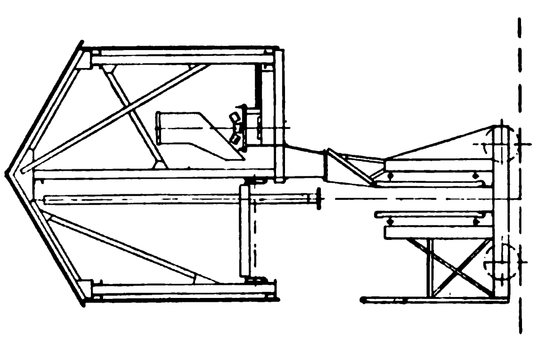


FIG. 425.

labouring the subject, the advantages of which are easily ascertained, it may be said shortly that compression of the slack increases the output of an oven 10 to 15 per cent, practically abolishes the breeze, and reduces the labour charges appreciably.

The process of coking occupies a period of from 18 to 26 hours, which varies with the percentage of moisture and volatile matter in the fuel charged. When the process is complete, the coke is discharged by means of a ram, which pushes the charge out in one mass on to the Solvay patent coke car, which is an inclined plane mounted on wheels, and so arranged that it can be moved to and fro in front of the ovens. As the coke is being pushed out the car is kept slowly moving, and in this way the batch is spread quickly and evenly over the whole surface of the car, and may be almost immediately quenched, thus ensuring a bright coke and a low percentage of moisture.

The coke is discharged on to a sloping hearth in preference to the old flat hearth, because this form enables the coke to be watered mechanically by the patent quencher, and admits of its being loaded into trucks or into blast furnace dandies with a minimum of labour. The quencher referred to is illustrated in fig. 427, and its use shows a great improvement in the appearance of the coke, which is as bright as "beehive," with an extremely low and uniform percentage of moisture. The whole of the coke from several plants is now quenched in the manner described without any hand watering whatever.

The sloping hearth may take two forms, according to circumstances. In cases where the coke is to be removed to a central station for stocking or loading, the patent coke car shown in fig. 427 is preferred. This car may be moved about by rope haulage, or it may carry its own motor and operator's cabin, according to circumstances. As the oven is discharged by the ram the coke passes through the quencher and falls upon the car floor, which is moved slowly forward so as to distribute the charge evenly over the floor. The car then runs forward to the loading or stocking station, as the case may be, and for this purpose it may be moved up an incline in order to obtain elevation. There the front gates are opened and the batch slides gently off the inclined floor.

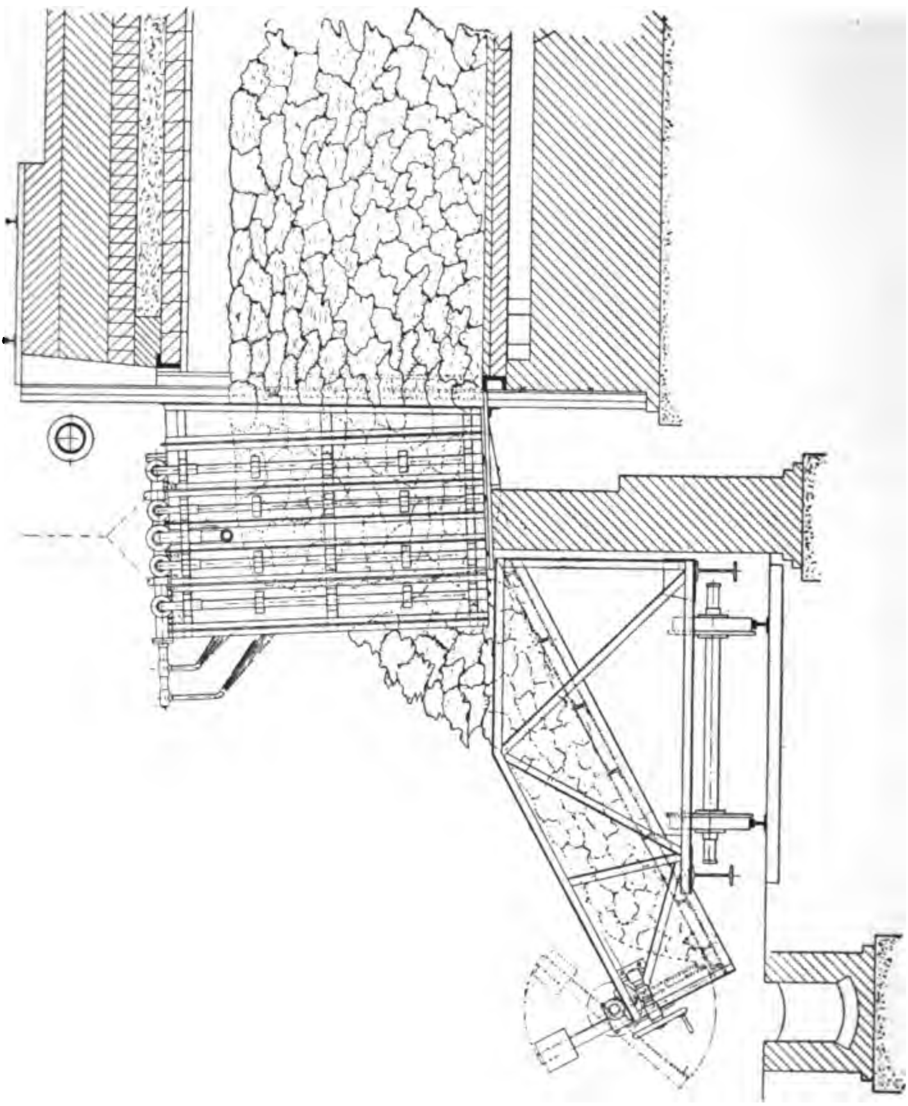


FIG. 427.—SHOWING THE COKE CAR AND QUENCHER.

The other form of sloping hearth adopted is a continuous plated slope, with or without retaining gates at the bottom, the slope being long enough to receive the length of a batch, and overhanging the truck or barrow in which it is to be received. The angle of slope adopted is the exact sliding angle for coke, so that the charge does not come tumbling down, but slides gently under the smallest impulse.

When the quenching is complete the car is moved by means of a wire rope or locomotive up an incline, where the contents are automatically discharged on to screens or into a bunker, these being so arranged that they are high enough to discharge into a railway wagon if required. This arrangement reduces the labour, and consequently the breakage, in handling the coke to a very great extent.

The greatly-increased yield and value of bye-products is due not only to the perfect construction of the ovens themselves, but in a large measure also to the efficiency of the plant for the recovery and subsequent treatment of the bye-products, which is so designed that all the various processes are absolutely continuous, and stoppages from deposits of naphthaline are unknown. In this way losses consequent on intermittent work are avoided, and labour is reduced to a minimum. In proof of this it may be stated that a plant to recover and treat the bye-products from fifty ovens can be worked by four men, two on the day shift and two on the night shift.

Much has been written and said about the increase of bye-product ovens causing a slump in the market for residuals. The fact, however, is that, with the exception of light oils, or benzols, the market is stronger at the present time than at any period since bye-product ovens have been erected in this country.

The Semet-Solvay bye-product recovery plant is well thought out, and as good as can be made for the work, the yields being the maximum obtainable.

Between six hundred and seven hundred of these ovens have been erected in Great Britain during the last few years, several of which have been largely extended since they were first erected.

For the new Semet-Solvay oven it is claimed that:—

1. It produces more coke per oven per day.

2. The coke is silvery, bright, and dry.
3. There is very little breeze or inferior coke.
4. Repairs are reduced to a minimum, and can be easily effected when required—only one oven need be put off at a time.
5. The oven flues are always tight and the yields of bye-products at their maximum.
6. Fuels can be coked by this system that have failed in all others.
7. The surplus gas from each oven, when burnt in a gas engine, for which it is well suited, yields continuously 30 to 40 brake horse power, varying with the quality of the fuel used.

CONCLUSION.

LITTLE now remains, before finally committing this volume to the tender mercies of the mining reader at home and abroad, but for the editors to express the hope that those into whose possession it may come will be

> "To its virtues very kind,
> And to its faults a little blind."

Looking back over those portions which represent their own efforts to complete the work of the late author, the editors are only too conscious of many imperfections and shortcomings.

Doubtless it will be considered by some that certain portions of the book might well enough have been omitted, while subjects of importance which are not dealt with—coal-cutting machinery, for example—ought to have found a place.

In common with the late author, although by no means to the same extent, the editors have had some experience of mining education and mining students, and their desire has been to put before their readers information which that experience leads them to believe is most wanted, and in a manner best suited to the requirements of the greater number of those into whose hands the book is likely to come.

By avoiding involved technicalities and intricate mathematical formulæ, they have endeavoured to make the subject dealt with intelligible to the practical reader whilst not being too elementary to be of some little value to the more advanced or highly-trained reader of scientific attainments.

It would be more than ungrateful not to acknowledge the debt of gratitude which the editors owe to the numerous firms who have rendered valuable assistance in furnishing particulars and illustrations of special appliances. Such assistance has in every case been most readily given, and the editors desire to record their thanks to the different firms whose names have appeared in the text in connection with the particular appliances with which they are associated.

More especially do they desire to acknowledge the valuable information placed unreservedly at their disposal by—

Messrs. Bellis & Morcom Limited.
Messrs. The British Insulated and Helsby Cable Company Limited.
Messrs. The British Thomson-Houston Company Limited.
The British Westinghouse Electric and Manufacturing Company Limited.
Messrs. Bruce, Peebles & Company Limited.
Messrs. Callender's Cable and Construction Company Limited.
Messrs. Joseph Evans & Sons.
Messrs. Fraser & Chalmers Limited.
Messrs. E. Green & Son Limited.
Messrs. Galloways Limited.
Messrs. W. T. Glover & Company Limited.
Messrs. Hathorn, Davey & Company Limited.
Messrs. Hadfield's Steel Foundry Company Limited.
Messrs. The Ingersoll-Sergeant Drill Company.
Messrs. Frank Pearn & Company Limited.
Messrs. The St. Helens Cable Company Limited.
Messrs. Simon-Carvès Limited.
Messrs. John Wood & Sons Limited.
Messrs. J. & E. Wright Limited.

The greater number of the original drawings are the work of Mr. Frank Percy, who has added considerably to the chapters on "Haulage" and "Screening." The chapters on "Electricity," "Haulage," and "Pumping" have been written by Mr. George H. Winstanley, who has added the matter relating to condensing plant and economisers. The bulk of the work appears practically as written by the late author, with such additions as have been necessary to bring it up to date.

A melancholy interest attaches to the series of excellent photographs appearing in the later pages of Chapter V., furnished by Messrs. Bruce, Peebles & Company Limited. These represent some of the electrical applications underground at the illfated United National Collieries at Wattstown, in the Rhondda Valley, where a recent explosion—10th July 1905—resulted in the loss of 120 lives. It is satisfactory to know

that the electrical appliances had nothing whatever to do with the explosion.

The great coal-mining industry—perhaps the most important of all British industries, because upon the success of its operations practically all the other industries depend for their existence—is one fraught with danger in many and varied forms. It is the duty of everyone engaged in that industry to strive to attain perfection, or the nearest approach to perfection, in the direction of efficiency and safety. A colliery is, or should be, a profit-earning concern; producing on the one hand a reasonable return for the capital expended in its development and equipment, and on the other providing a means of livelihood for three-quarters of a million of the dwellers in the United Kingdom.

Conditions of comparative comfort and safety are not difficult to attain in the working of a colliery, nor are such conditions incompatible with remunerative profit, economy, and efficiency. At the present time these conditions depend very largely—in the future they are likely to depend still more largely—upon the mechanical equipment of the colliery. In this respect the modern colliery is a wonderful improvement upon the colliery of even twenty-five years ago; the next quarter of a century will see still greater progress and advancement, and it is the hope of the editors (such, they know, was the hope of the late author) that this work may find some little sphere of usefulness in connection with that progress and advancement in the "Mechanical Equipment of Collieries."

FINIS.

INDEX.

D

F

O

P

T

Printed and Bound by James Collins & Kingston Limited, Southgate, Manchester.

The Pepper Mill Brass Foundry Co.

BRASSFOUNDERS & COPPERSMITHS,

WIGAN, ENGLAND.

Telegrams—"PEPPER, WIGAN."

MAKERS OF

ENGINEERS' BRASSWORK

of all descriptions,

COCKS, VALVES, LUBRICATORS, ASBESTOS-PACKED FITTINGS, &c. COLLIERY WINDING INDICATORS,

and other

COLLIERY SPECIALITIES.

CONTRACTORS TO HIS MAJESTY'S GOVERNMENT.

Smallman Patent Haulage Clip.

NEW MODEL: 1902. Patented in Great Britain and abroad.

This clip, famous for the excellence of its manufacture, is supplied in seven sizes and with various couplings.

The catch that locks the lever is not always wanted.

Particulars of the automatic detacher and special curve rollers are contained in the recent circular.

PATENTEE AND SOLE MANUFACTURER:—

JAMES W. SMALLMAN,

NUNEATON, England.

HADFIELD'S STAND AT THE COLLIERY EXHIBITION, LONDON, JUNE 1904.

We Manufacture Colliery Requisites of every Description.

HADFIELD'S Steel Foundry Co. Ltd. SHEFFIELD.

WE ARE THE SOLE MAKERS OF

HADFIELD'S PATENT "ERA" MANGANESE STEEL,

Which is Recognised to be the Supreme Material for

ALL CASTINGS that have to WITHSTAND ABNORMAL WEAR and TEAR.

20,000 COLLIERY TUB WHEELS—A RECORD WEEK'S WORK.

[illegible]